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Volume I

AIRCRAFT FIRE SENTRY VOLUME I - SUMMARY

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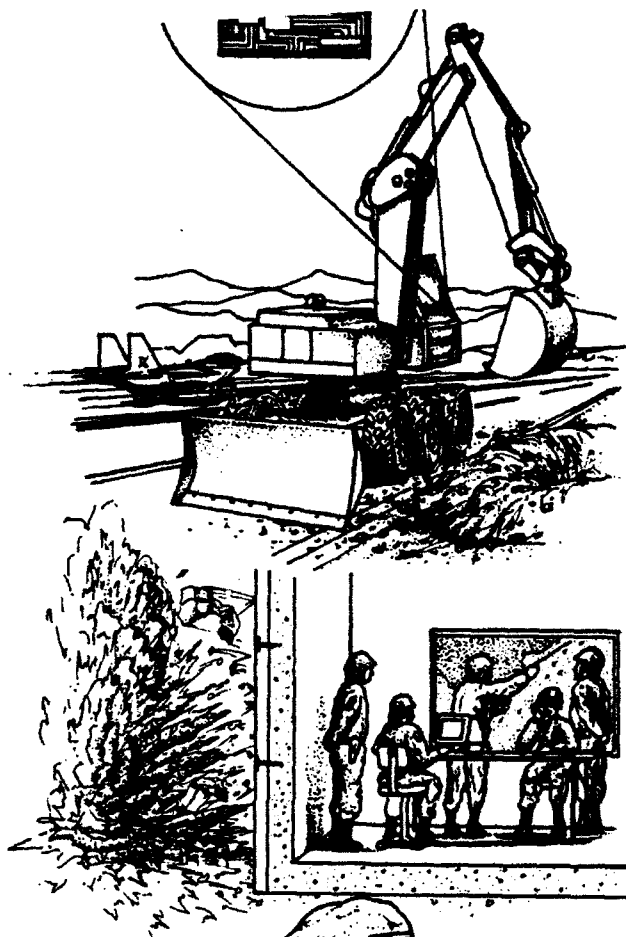
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13. ABSTRACT (Maximum 200 words) This report summarizes the development of an Aircraft Fire Sentry (AFS) system. The AFS is designed to automatically detect a fire in the cargo bay of large cargo aircraft, provide an audio and visual alarm locally, and remotely notify the nearest fire department by radio frequency link. The basic design philosophy in developing the AFS was to use commercially available fire detection hardware and radio transmitters/receivers. The finished assembly is to be lightweight and portable. The AFS is to be deployed onboard parked aircraft and left to sense fire stimulus for up to 60 continuous hours in the self-powered mode. A prototype model was designed, built, and tested for performance and reliability.					
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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this effort was to develop a portable fire detection and notification system that could be placed aboard parked, unattended large cargo aircraft. The system, referred to as the Aircraft Fire Sentry (AFS), should be light, efficient and easily deployable. Included in the development were phases defining the threats, detection/notification solutions using current commercial hardware, assembly, testing and evaluation of the concepts.

B. BACKGROUND

The system was conceived as a means of protecting national assets, in terms of large-frame cargo aircraft, from damage or catastrophic loss due to fire. Many of today's tanker and cargo aircraft are no longer in production. It is necessary to protect these assets while they still have a useful life. Actual loss of these large aircraft remains low; however, the threat of loss due to fire is always present. All of these aircraft have on-board fire detection and suppression systems to some degree integral with their airframes or powerplants. However, they are only functional when the aircraft is running. The AFS fills the need for fire detection and notification while the aircraft is unattended.

C. SCOPE

The AFS research and development program consisted of five major tasks:

Task 1 -- Feasibility Analysis and Conception Design. This effort included surveys to determine fire protection requirements, literature searches of available technologies that could be adapted for AFS purposes, and the development of conceptual designs that would lead to one or more breadboard systems which could be tested. Cost effectiveness with respect to purchase, installation, operation and maintenance was considered for each configuration.

Task 2 -- System Design and Component Testing. As a result of Task 1, the most desirable AFS configuration was assembled and tested. Results and analyses were reported and recommendations made for a prototype design.

Task 3 -- Prototype Construction, Development, Test and Evaluation. Following a final design review, a prototype AFS was assembled, tested and evaluated.

Task 4 -- Technical Report. This report, a summary of all work completed.

Task 5 -- Draft Performance Description. A draft performance description was prepared describing performance standards for each component of the AFS.

This final technical report is comprised of two volumes. Volume 1 summarizes the entire project. Volume 2 includes the detailed design and testing reports for Tasks 1, 2 and 3, and the Draft Performance Description.

D. METHODOLOGY

Evaluation methodology used to determine preliminary and final designs of the AFS were based on system performance, size, ease of deployment, availability of components and cost. Each of these factors were weighted approximately the same.

Three original concepts were developed after Task 1. Based on the above criteria and two formal design review meetings, the AFS evolved into the prototype unit. Representatives from the Air Force, Applied Research Associates, Inc. and the fire detection/notification industry were in attendance at these design reviews. AFS system requirements were met by open discussion and design of the most responsive, efficiently-sized assembly.

Two actual working models were built and tested -- a small scale "breadboard" design and a "prototype". Based on results from the test on the small scale AFS, improvements were incorporated into the prototype. A final evaluation was made after the prototype test series.

E. TEST DESCRIPTION

Objective test series were conducted on both the small scale and prototype models. These tests included system response times, smoke obscuration and temperature monitoring during live fires, radio frequency quality and distance testing and proper hardware operation. Tests were conducted at Fairchild AFB and at ARA's remote test site (live fires) and laboratory.

F. RESULTS

A working prototype model AFS was provided for Task 3. The result is an assembly that is 14 inches square by 20 inches high, and weight 39 pounds. It is fitted with a single ultraviolet (UV) flame sensor, two wireless remote photoelectric smoke detectors and a manual pull station for initiating alarms. The prototype is self-powered by a 12 VDC battery, and must be fully charged (by AC) prior to deployment. This model meets the requirements of simultaneous fire/smoke stimulus sensing and will report such conditions to the nearest fire department via radio frequency link.

It was documented that this configuration will transmit 1.1 miles while deployed inside an actual aircraft. System response times ranged from instantaneous (flame recognition by UV sensor) to 237 seconds (smoke density increasing at photoelectric detector).

The AFS can be carried by one person and deployed in under 5 minutes. Setup involves bringing it onboard, placing it mid-bay, locating the wireless remote smoke detectors, connecting the system antennas (2) and placing the hard-wired siren/strobe unit outside the aircraft. Once powered on, the AFS will continuously sense for fire conditions until its internal battery power is depleted (36 - 60 hours, depending on conditions and battery size).

G. CONCLUSIONS

The AFS has been demonstrated as a viable, effective means of detecting fires aboard unattended cargo aircraft.

Because of its portable design and ease of deployment, it can also be used in other situations. For example, anywhere a temporary system might be needed, whether it be aircraft, building or tent. The distance between the AFS and the fire department is critical. The proper antenna and/or repeated station(s) must be selected as the situation requires.

H. RECOMMENDATIONS

The AFS system could be produced and used as is. However, the system could benefit from further development in terms of incorporating the latest fire detection hardware and trimming of its overall size and weight. It is also recommended that for any production models, all three types of detection sensors (smoke, heat and flame) be integrated into the system.

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PREFACE


This report was prepared by Applied Research Associates, Inc., Rocky Mountain Division, Lakewood, Colorado under SETA Contract Number C F08635-88-C-0067, Subtask 3.14.1, for the Air Force Civil Engineering Support Agency (AFCEA), Tyndall AFB, Florida 32403-5319.

The AFCEA Project Officer was Mr. Charles W. Risinger. The period of performance was between 17 August 1990 and 17 August 1992.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Services (NTIS), at NTIS, it will be available to the public.

This technical report has been reviewed and is approved for publication.


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SECTION I

INTRODUCTION

A. OBJECTIVE

The research effort described in this final technical report represents work done by Applied Research Associates, Inc. (ARA) for the Air Force Engineering Support Agency (AFCEA) between August 1990 and August 1992. The purpose of the effort was to design, build, and test a portable fire detection and notification system to be used aboard unattended large cargo aircraft. The system is referred to as the Aircraft Fire Sentry (AFS).

B. BACKGROUND

The system was conceived as a means of protecting national assets, in terms of large-frame cargo aircraft, from damage or catastrophic loss due to fire. Many of today's tanker and cargo aircraft are no longer in production. It is necessary to protect these assets while they still have a useful life. Actual loss of these large aircraft remains low; however, the threat of loss due to fire is always present. All of these aircraft have on-board fire detection and suppression systems to some degree integral with their airframes or powerplants. However, they are only functional when the aircraft is running. The AFS fills the need for fire detection and notification while the aircraft is unattended.

C. SCOPE

The program was essentially conducted in three different phases associated with project tasks 1, 2, and 3, each being a milestone in the program. Detailed technical reports were produced at the end of each task. These reports are included as Appendices A, B and C for this document. Appendix D contains the draft performance description (Task 5). This final technical report (Task 4) summarizes progress during the entire project and highlights the important technical issues and findings. Specific details of any given task can be found in review of the appropriate appendix.

The initial objectives of the program were to design, construct, test and evaluate a portable fire sentry protection system capable of automatic fire detection, fire suppression and remote notification of fires aboard large unattended aircraft. The AFS system must be simple to use and deploy. The installed system must not interfere with the normal activities that take place around a cargo aircraft. Maintenance of the system should be minimal; and its operation should be universal between aircraft. "Smart" detection schemes were to be developed by tying together sensors such that the false alarming rate was extremely low or nonexistent. In addition, the system was to be designed to extinguish Class A, B and C fires.

After the AFS feasibility study (Task 1), the Air Force changed the scope of the research. This change shifted emphasis away from expensive and complicated "smart" detection towards application of proven fire detection with commercially available hardware and remote notification, and eliminated the suppression requirement for the AFS entirely.

The AFS research and development program consisted of five major tasks:

Task 1 -- Feasibility Analysis and Conception Design. This effort included surveys to determine fire protection requirements, literature searches of available technologies that could be adapted for AFS purposes, and the development of conceptual designs that would lead to one or more breadboard systems which could be tested. Cost-effectiveness with respect to purchase, installation, operation and maintenance should be considered for each configuration.

Task 2 -- System Design and Component Testing. As a result of Task 1, the most desirable AFS configuration would be assembled and tested. Results and analyses would be reported and recommendations made for a prototype design.

Task 3 -- Prototype Construction, Development, Test and Evaluation. Following a final design review, a prototype AFS would be assembled, tested and evaluated.

Task 4 -- Technical Report. This report, a summary of all work completed.

Task 5 -- Draft Performance Description. Prepare a draft performance description describing performance standards for each component of the AFS.

Deliverables were: (1) the written documents required from each of the five tasks, and (2) monthly progress reports. In addition, ARA provided the prototype AFS system to the Air Force when the testing was completed.

SECTION II

TASK 1 -- FEASIBILITY ANALYSIS AND CONCEPTUAL DESIGN

A. TASK 1 DESCRIPTION

The Statement of Work requirement for Task 1 was to determine the fire protection requirements of parked large-body aircraft. In addition, a survey of current technologies available to accomplish AFS system goals was also to be conducted. At least one conceptual design for the AFS was to be proposed for development and testing in later tasks.

The scope of the Task 1 effort consisted of soliciting product information from vendors of fire detection and suppression equipment for analysis and conceptual design criteria, viewing large-frame aircraft which the final system is targeted to protect, and visiting with Air Force fire departments to get their inputs on the system's design. Additional information was obtained from previous reports covering past research performed on the topic of fire protection systems, and from the Environmental Protection Agency (EPA) concerning the impact of firefighting agents on the environment.

The primary focus of this program was to develop a system which will be widely accepted for use. In the past, the major focus of fire sentry system research has been on the detection and suppression of fires. These studies show the effectiveness of detectors to recognize fires and suppression systems to put fires out. This program uses the information gained from past research programs to develop a system which meets all the necessary fire extinguishment and false alarm immunity requirements as well as the human interfacing requirements.

B. TASK 1 ACCOMPLISHMENTS

To determine the protection requirements of large-frame cargo aircraft, four Air Force bases (Norton, Travis, March, and McCord) were visited to view representative aircraft and discuss the requirements of the system with the base fire departments. The information from the Air Force bases was incorporated, along with data from accident reports on past military and commercial fire events to derive the final requirements.

Four different types of large-frame cargo aircraft were reviewed at the various Air Force bases. A C-141 aircraft was viewed at Norton AFB and McCord AFB, a KC-10 and a C-130 were viewed at March AFB, and a C-5 was viewed at Travis AFB. Particular facets of each aircraft were observed to determine their possible effects on the design of the fire sentry system. These included the size of the cargo bay, the number and sizes of openings into the cargo bay, available equipment which could be used, available places in which to install the fire sentry system, the types and sizes of cargo carried, how the cargo

might impede the installation or removal of the fire sentry system and how the fire sentry system might impede the installation or removal of cargo.

A summary of the technical findings of each of the four types of aircraft surveyed can be found in Appendix A Section 3.1. Essentially, the volumes of cargo bays to be protected range from 4500 cubic feet (C-130) to 34,800 cubic feet (C-5). Each aircraft has differing locations and numbers of access by ports, emergency exits, crew and cargo doors.

Aircraft fire sentry system operational requirements were developed as a result of the survey of aircraft in combination with a review of fire threats to aircraft and the System Operational Requirements Document (SORD 201-84-1). The requirements at this point in the project were:

1. The system must be designed knowing that it is going to be used by air crewman and firefighters on any flight line throughout the world. Personnel using the equipment may be wearing gloves, firefighting gear, or chemical warfare gear. Size, weight, shape, and appearance are all critical factors which must be addressed.

2. The system and all of its components must be rugged, capable of withstanding extreme abuse and mishandling. All components must meet military standards for shock, vibration, temperature, pressure, adverse weather, humidity, fungus, hazardous atmospheres, EMI, and reliability.

3. The system must be easily assembled, installed, removed, and disassembled. Installation or removal of the system should not take more than two trained personnel, working for only a few minutes, regardless of the aircraft or the cargo being loaded.

4. The system must be modular in design so that it can be used to protect any large-frame aircraft.

5. The system must have a low false-alarm rate and a high detection rate.

6. The system must provide automatic alarm notification to the fire station via an RF communication link. System must also provide audible and visual alarms to alert nearby personnel.

7. The system and all of its components must operate off rechargeable batteries and must be capable of continuous operation without a recharge for a minimum of 72 hours.

8. System must not interfere with normal aircraft activities (primarily the loading and unloading of cargo) and must not require any permanent modification to the aircraft.

9. System must use commercially available or Air Force base common components wherever possible.

10. System must be capable of suppressing Class A, B, and C fires by maintaining required agent concentration levels in all areas of the cargo bay for a minimum of 5 minutes with all nonemergency access doors except cargo bay doors fully open.

11. System must include built-in testing capabilities to verify the operational status of the system before each use and during normal operations to aid in the trouble shooting and repair of an out-of-order system.

12. The detection system and the suppression system must be operationally independent of one another. That is, each system must be able to operate without the use of the other. The suppression system shall be activated either manually or by an electronic signal from the detection system.

C. INDUSTRY RESEARCH -- FIRE DETECTION/COMMUNICATION

Industry research was performed to determine the availability of equipment which could be used on this program. The main areas of the research were focused around detector and detection systems, extinguishment systems, and communication systems. Of the systems and components investigated, almost all are designed to be used in commercial or industrial applications, primarily for building protection. Because of the special nature of the fire sentry system, the use of any components found require some customizing to be used on this program.

The commercially available fire detection techniques include smoke, flame and heat detection. Smoke detectors fall into two categories: a) ionization, and b) photoelectronic. They are both effective when matched to their proper environment. However, both types are susceptible to false alarm stimuli such as fog or dust. Ionization detectors are also susceptible to false alarming due to RF and voltage transients. Photoelectronic units have an advantage in that smoke does not actually have to come in contact with detector elements, in which case the electronics can be more easily protected.

Flame detection is offered by two different means of sensing: a) infrared (IR) and b) ultraviolet (UV). Both sensors measure the radiant energy emanating from a burning substance. Under their own unique conditions, both sensors are susceptible to false alarming stimuli. Because UV and IR detectors have virtually no common false alarm sources, when used together they produce flame detection with an overall lower false alarm rate. Additionally, these sensors can only respond to a fire that is in their "field of view".

The last type of fire detectors being considered are the heat detectors which also come in basically two varieties: a) fixed temperature and b) rate of rise. Both trigger when

their thresholds, either maximum temperature or the rate of temperature rise exceeds a preset standard. The main disadvantage with these sensors is that they have a limited operating radius (spot measurement) and are slow to respond.

To meet AFS objectives that fire detection be extremely reliable, detector "modules" utilizing multiple sensors would be developed. Each module would employ at least one type of smoke, flame and heat sensor. The use of different detectors increases the probability of early detection, and with the use of intelligent ("smart") processing of the data provided by the detectors, minimize false alarming. Fire detection devices are designed to be used in areas generally void of any false alarming stimuli. When false alarm stimuli are present, individual detectors are inherently unreliable. Smart processing logic of data available from the sensors compares the data and makes decisions whether or not a real fire is present.

Once the fire is detected, news of the fire must be transmitted to the base fire department. The most practical way is by radio frequency (RF). Manufacturers of communication systems were surveyed for applicability of their equipment for AFS purposes. A listing of these manufacturers can be found in Appendix A, Section 3.6.3. Detailed information concerning any part of this technology survey can be found by reviewing Appendix A. Ultimately, it was Monaco Enterprises, Inc. equipment that was chosen for the VHF RF communication portion of the AFS. They were chosen due to the wide use of their communication equipment already installed at many U.S. Air Force bases.

D. INDUSTRY RESEARCH -- FIRE SUPPRESSION

The purpose of the suppression system on the AFS would be to release agent into the cargo bay, flooding it and maintaining the proper concentration level for up to 5 minutes until the fire department could arrive. The system must be effective against Class A (wood, paper), Class B (flammable liquids), and Class C (electrical) type fires. The current manufacturers of extinguishment systems offer water, foams, dry chemicals, halons or CO₂ as fire-suppressing agents. It was concluded early on that water, foam, or dry chemicals would be impractical for AFS purposes due to their ineffective dispersion characteristics in a cargo bay and the mess and possible damage they leave behind after use. This leaves halons or CO₂ as options for AFS considerations.

Extinguishing system manufacturers were surveyed for applicability of their halon and CO₂ equipment to AFS. Halon 1211 is widely used throughout the Air Force as the agent for the small portable flight line extinguishers. It is generally considered a streaming local application agent, not intended for total flooding purposes. Halon 1301 has been a safe (low toxicity to humans) and effective total flooding agent for suppression of fires for many years. Countless thousands of Halon 1301 systems are in use for the U.S. Services and worldwide commercial industries.

CO₂ is another effective means of suppressing fires by total flooding application. CO₂, however, forms a fog as it is dispersed and displaces oxygen, making it potentially

lethal to anyone in the area. All of the technical details found during the research of suppression agents can be found by review of Appendix A, Section A.1.

The disadvantages of using halons are that they are relatively expensive to recharge after every use (the cost will increase dramatically as production is phased out and an additional tax is added to every pound sold), they are harmful to the environment, by-products of extinguishment are highly toxic, and halons will no longer be available for use after the year 2000.

1. Montreal Protocol and Clean Air Act

Halons will no longer be available because of the Montreal Protocol and the Clean Air Act of 1990. In Montreal in September 1987, 24 nations, including the United States, signed an agreement to reduce and eventually eliminate the use of chlorofluorocarbons (CFCs) and halons which deplete the earth's ozone layer. This agreement known as the Montreal Protocol was signed by eight additional countries by June 1988. The agreement was further strengthened in June 1990 when the Montreal Protocol was revised and now supported by 93 countries. The new agreement set the stage to phase out CFCs and halons and restrict other ozone depleters by the year 2000. With respect to halons, the agreement set to reduce halons by 50 percent by 1995 with complete phaseout by 2000. This includes Halon 1301 and Halon 1211.

Near the end of 1990, the United States passed a bill called the Clean Air Act of 1990, which strengthened the provisions of the Montreal Protocol by requiring a complete phase out of CFCs and halons by 2000. A major impact of the bill is the accelerated phasing out of halon agents. The bill besides banning the production and distribution of halons after the year 2000, also imposes a tax per pound sold based on the agent's ozone depletion potential (ODP). Halon 1301 has the highest ODP of 10.0 and would be taxed the greatest followed by Halon 2402 with an ODP of 6.0 and Halon 1211 with an ODP of 2.0. Only those halon or related agents with an ODP of less than 0.2 are allowed after 2000.

The impact of the Montreal Protocol and the Clean Air Act of 1990 is causing serious consequences in the firefighting industry. The Department of Defense, especially the Navy and the Air Force, use extensive numbers of halon firefighting systems for the protection of aircraft and ships. Being so effective at fighting fires with few drop-in alternative agents available or expected to be produced in the near future, the demand for halon systems is increasing.

The first major impact of the Montreal Protocol is that the cost of using or recharging a halon system is increasing due to increased demand, decreased supplies, and added taxes. While many commercial industries, as well as government agencies, have been trying to develop acceptable replacement agents, the long-term characteristics of these agents will not be known for many years. Due to incompatibilities with halons, switching over to replacement agents currently or potentially available still requires a redesign of the extinguishment system.

The halon replacement agents being considered for use on this program are the replacement agents for Halon 1301 and Halon 1211. Two types are being considered. The first type is a direct drop-in replacement for either agent. The second type has operating and firefighting characteristics similar to Halon 1301 or Halon 1211 but may require some modifications to existing extinguishment systems or a totally redesigned extinguishment system.

The Great Lakes Chemical Corporation has developed a product which is currently available for limited use, called FM-100, which has physical characteristics somewhere between Halon 1301 and Halon 1211 and an ODP within the acceptable limits set by the EPA. However, its lethal toxicity level is worse than Halon 1211 making it only usable in normally unoccupied areas. Initial tests of FM-100 have shown that its firefighting characteristics require approximately 0.5 percent higher concentrations to extinguish a fire as compared to Halons 1301 and 1211.

The DuPont Corporation is developing products to replace both Halon 1301 (FE-25) and Halon 1211 (FE-232). However, these products are still undergoing developmental testing, evaluation, and characterization, and will not be available for use until the later part of this decade. Table 1 summarizes extinguishing agent characteristics and costs.

The impacts to this program are that a decision must be made as which agent the system will be designed around. The initial choice is to use one of the halon agents (Halon 1301). Their operating characteristics and firefighting capabilities are well suited for this application and are superior to any other agent available. However, the system can only be designed around an existing halon agent if it is assumed that either a drop-in replacement agent will become available before the existing agent can no longer be used, or the system or the agent will be exempted from the provisions of the Montreal Protocol and the Clean Air Act (even at the cost of additional high taxes and reduced production). Neither scenario is likely. Due to the pending difficulties with halons and replacement agents at this time, CO₂ remained a viable option for the suppression portion of the AFS system accepting the safety risks involved in the event of accidental or purposeful discharge.

E. AFS CONCEPT DESIGNS

Three AFS concept designs were produced as a result of the Task 1 effort (Figure 1). The designs were broken down into three functionally different areas: internal detection, internal suppression and the external cart.

Configuration 1 uses multiple detector "modules," each with multiple sensors, distributed throughout a given cargo bay. The number of modules varies depending on the size of the bay, but enough such that overlapping for detector sensors is achieved, thus protecting the entire bay. More specifically, each detector module consists of a small

TABLE 1. FIREFIGHTING AGENT COMPARISON

Characteristic	CO2	Halon 1301	Halon 1211	FM-100	FE-25	FE-232
1. Chemical Formula	CO2	CF3Br	CF2C1Br	CHF2Br	CF3CHF2	CF3CHC12
2. Molecular Weight	44.01	148.90	165.40	130.90	120.02	152.90
3. Boiling Point (F)	-109.30	-72.00	24.80	5.00	-55.30	82.20
4. Liquid Density at 70F (lbs/ft ³)	60.00	98.00	114.00	97.00	78.00	91.15
5. Vapor Pressure at 70F (psia)	850.00	214.00	36.70	59.00	190.00	13.00
6. Extinguishing Concentration (%) (1)	34.00	3.50	3.80	3.90	10.10	7.10
7. Extinguishing Material (lbs) (2)	500.00	200.00	250.00	250.00	550.00	600.00
8. Agent Cost (3)	\$250.00	\$1,200.00	\$1,625.00	\$3,500.00	\$9,900.00	\$3,900.00
9. Acute Toxicity (4)	(5) 0.00	800,000	100,000	108,000	>>100,000	32,000
10. Ozone Depletion Potential	0.00	10.00	3.00	0.19	0.00	0.02
11. Comparisons						
a. Clear Vision at Discharge	No	Yes	Yes	Yes	Yes	Yes
b. Nitrogen Required	No	Yes	Yes	Yes	Yes	Yes
c. Size of Storage Bottles	40.7 in ³ /lb (11.7 ft ³)	24.7 in ³ /lb (2.85 ft ³)	21.6 in ³ /lb (3.13 ft ³)	N/A	N/A	N/A
d. Availability of Agent	Many Sources	Limited (6)	Limited (6)	New Product	-1995	-1991
e. Toxicity	None	Low	Moderate	Sole Source	Moderate	High

NOTES: (1) N-Heptane, % volume
(2) Assuming 10,000 cubic foot sealed volume -- Quantity of material required to meet recommended concentrations

- a) CO2 34%
b) Halon 1301 5%
c) Halon 1211 5%
d) FM-100 6% (Estimated)
e) FE-25 15% (Estimated)
f) FE-232 10% (Estimated)

(3) Assuming wholesale costs

- a) CO2 \$0.50 / lbs
b) Halon 1301 \$6.00 / lbs (Not including tax)
c) Halon 1211 \$6.50 / lbs (Not including tax)
d) FM-100 \$14.00 / lbs (Estimated)
e) FE-25 \$18.00 / lbs (Estimated)
f) FE-232 \$6.50 / lbs (Estimated)

- (4) ALC or LC(50) Rats: 4 hrs-ppm
(5) Although non-toxic, extinguishment concentrations are lethal.
(6) Being phased out. Not available after year 2000.

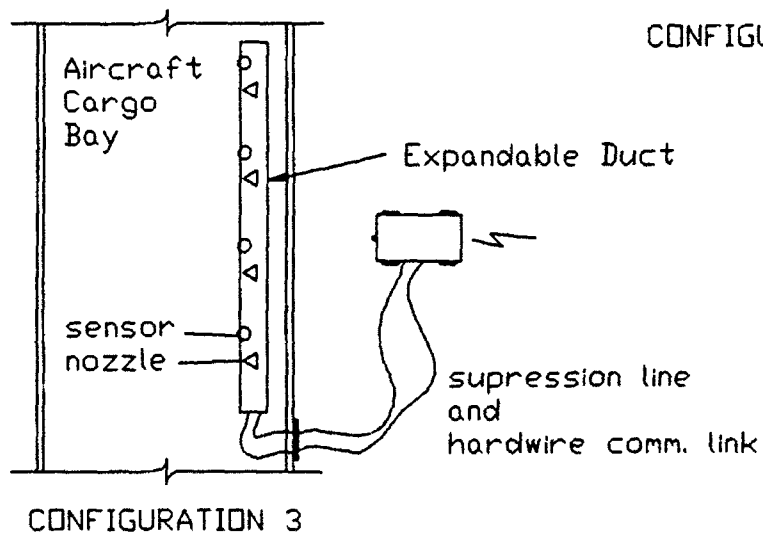
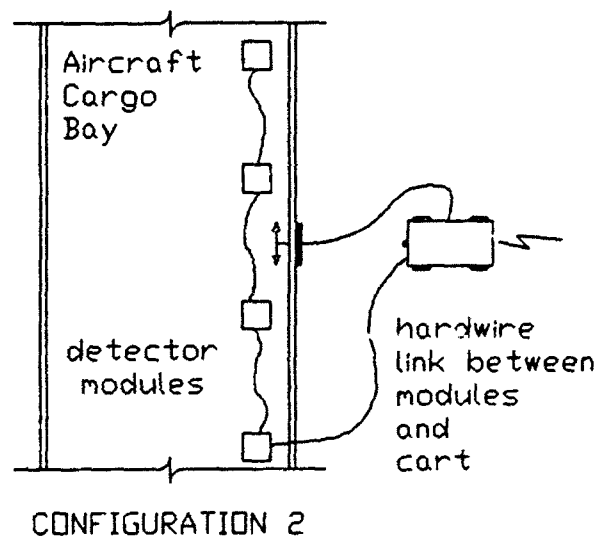
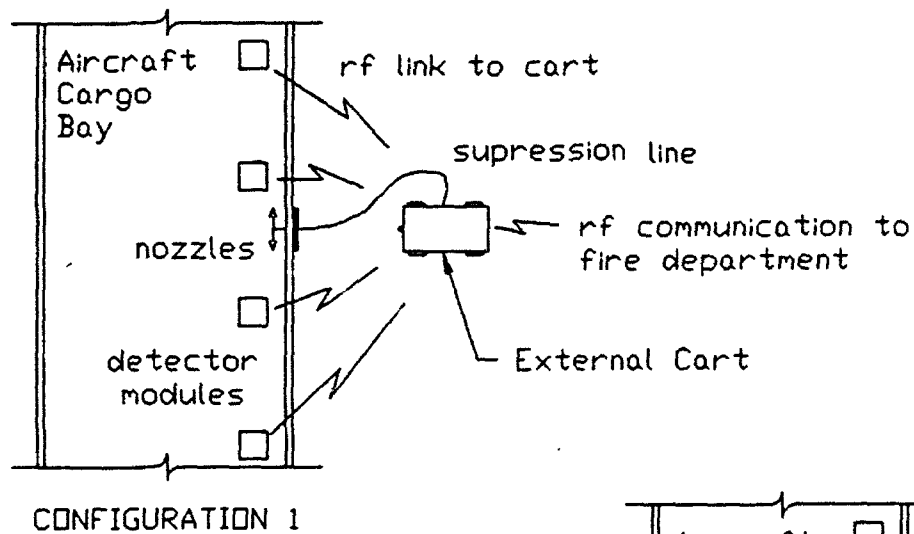


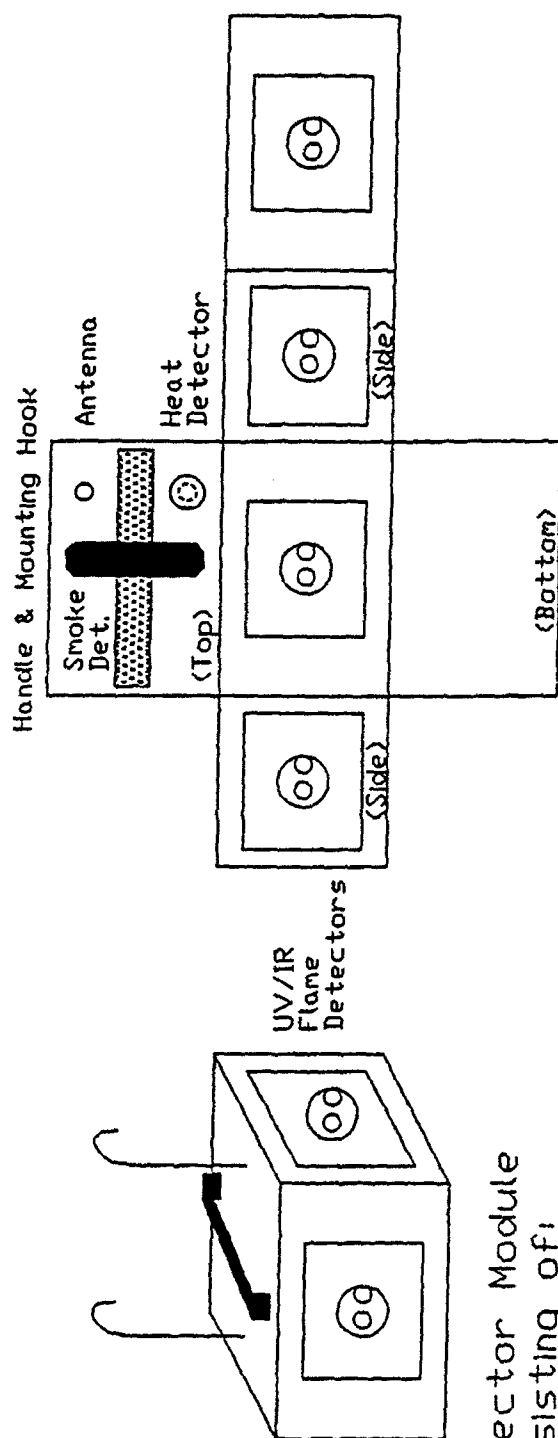
Figure 1. Block Diagrams of Proposed AFS Concepts

sealed enclosure approximately 8 inches by 12 inches on a side (Figure 2). Four UV/IR flame detectors are mounted orthogonally on the four sides; a photoelectric smoke detector is mounted on the top along with a heat detector (optional). A small fan is used to draw air through the smoke detector to increase its sensitivity. The system is installed in the cargo bay by hanging from either the walls or the ceiling, or setting it in a place where the detectors have an unobstructed view of the bay. The outputs of the sensors are digitally encoded and transmitted to the external cart upon request. The power of the transmitter would be approximately 1 milliwatt with a maximum range of 300 feet. The module is powered up with a rechargeable battery. The detector modules perform no processing except the encoding of the data. The external cart shall request updates from each detector module a minimum of 1 to 10 times a second. The system is flexible in design so that any number of detector modules can be installed in an aircraft. It is anticipated that four modules would be required for a C-5, C-141, and KC-10, and two modules for a C-130.

The internal suppression dispersion system for this configuration consists of agent discharge nozzles mounted to the inside of a "dummy" replaceable emergency exit door (Figure 3). Once the door is installed, a quick-disconnect hose would be attached between the door and the external cart containing the bulk of the suppression system hardware. Multiple agent dispersion locations (multiple doors) would be required for proper total flooding characteristics on the larger aircraft. A pressure relief valve would be provided in the replacement door to vent excess cabin pressure in the event of agent discharge into a completely sealed aircraft (all crew and cargo doors shut).

The final part of the Fire Sentry design is the external cart. The external cart is responsible for storing all of the extinguishment agent, and providing all the processing of the detector data, the necessary communication links between the detector modules and between the fire station, and visual and audible alarms (Figure 4). The basic design of the cart is independent of the type of extinguishment agent used, and could be easily retrofitted to accommodate any agent. The body of the cart is used to hold the cylinders containing the extinguishing agent. The cylinders while piped together to act as a single source of agent, are separated into two groups. The first group of cylinders is used to generate the initial concentration levels of agent inside the cargo bay. The second group is used to maintain the concentration levels for the required duration. The external cart is also equipped with an additional external hose which provides an additional flight line fire extinguisher capability.

The cart is powered by on-board batteries. When the system is not in use, a battery charger is provided to recharge the batteries. The battery charger operates automatically when connected to either aircraft power or a standard wall socket. The cart provides a special location to store the detector modules. The location is designed to automatically recharge the detector modules' batteries and provide additional protection from the elements. The cart is also equipped with a display panel showing the status of the system and printed instructions to show operation of the system to an untrained user.

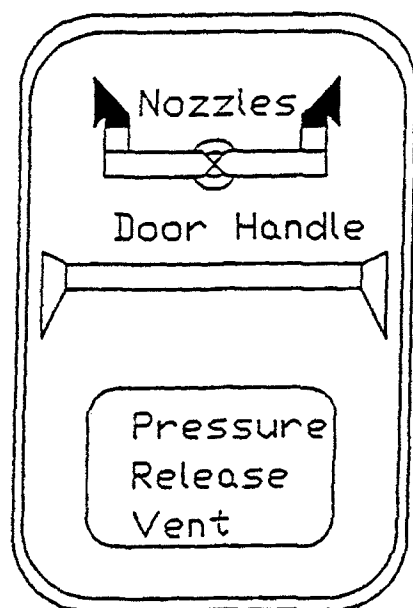


Detector Module

Consisting of:

1. 3 - UV/IR Flame Detectors
2. 1 - Smoke Detector
3. 1 - Battery (Internal)
4. 1 - Tx/Rx FM Communication link
5. 1 - Antenna
6. 1 - Heat Detector

Figure 2. Preliminary Detector Module



Aircraft Fire Sentry Door
Replacing Aircraft Emergency Exit Door

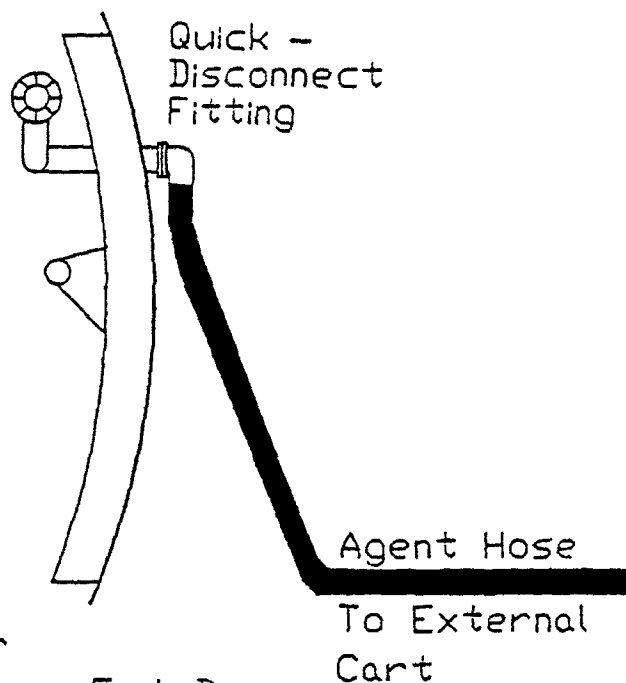
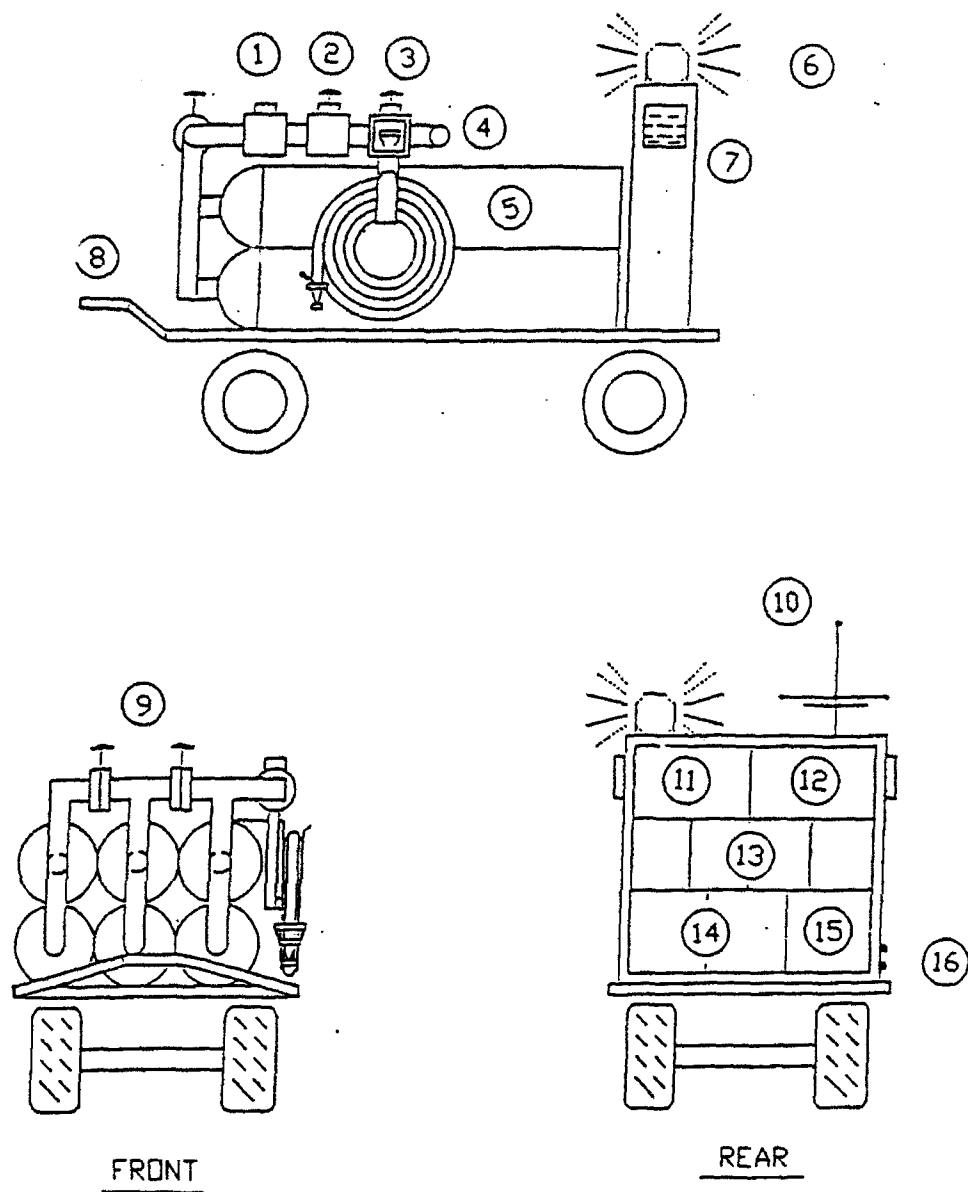


Figure 3. Dispersion System 1



- | | |
|-----------------------------|------------------------------------|
| 1. AGENT FILL PORT | 9. VARIABLE DRIFICES |
| 2. AGENT DISCHARGE VALVE | 10. ANTENNA |
| 3. HAND HOSE CONTROL VALVE | 11. MASTER CONTROL PANEL |
| 4. DISCHARGE HOSE CONNECTOR | 12. TRANSMITTER/RECEIVER PROCESSOR |
| 5. AGENT CYLINDERS | 13. DETECTOR MODULE STORAGE |
| 6. STROBE LIGHT | 14. BATTERIES |
| 7. SIREN | 15. POWER SUPPLY/BATTERY CHARGER |
| 8. STANDARD HITCH | 16. AC CONNECTOR |

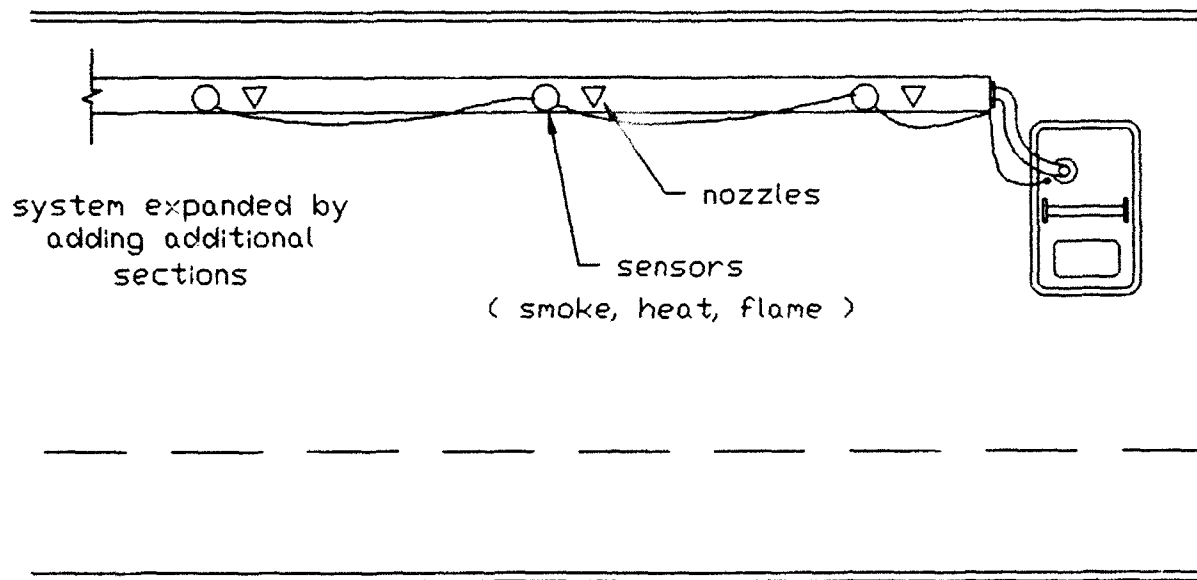
Figure 4. External Cart

Configuration 2 concept is similar to Configuration 1 except that all power and communications between the detector modules and the external cart is achieved by a hard wire link instead of RF. This simplifies the design considerably, reduces its costs, makes the modules lighter and smaller, and increases the time which the system as a whole can remain active between recharges. However, it adds an additional obstruction within the cargo bay.

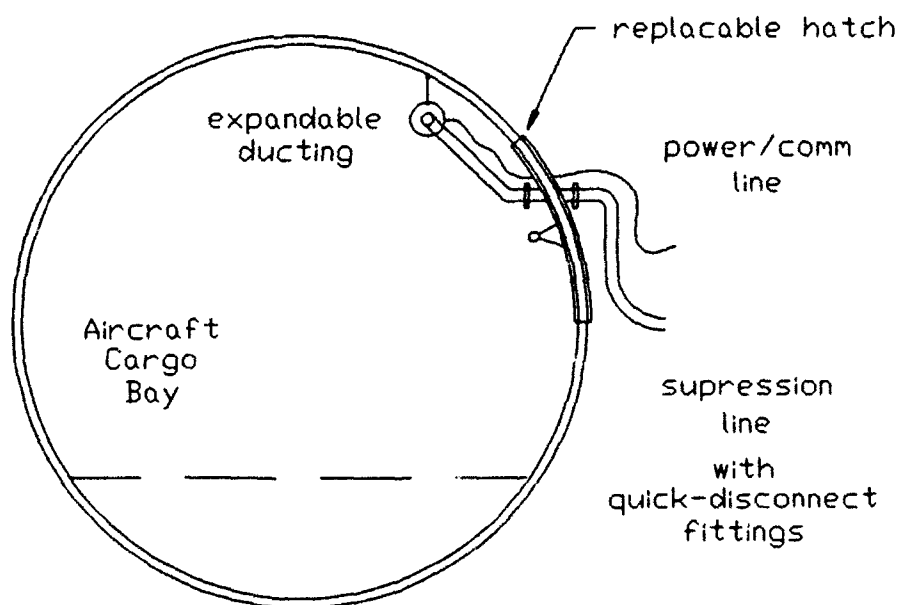
Configuration 3 combines the detection sensors and the suppression agent dispersion system together in an expandable telescoping tubular duct which can be installed at ceiling-level inside the cargo bay (Figure 5). This system is used as necessary to provide additional nozzles spread out along the length of the cargo bay to disperse the agent. For the combination module, both the agent hose and the detectors are mounted inside a lightweight protective housing which protects both the detectors and the nozzles from accidental damage. Several nozzles are mounted along the length of the hose. Each end of the hose is fitted with a self-sealing quick release connector. Several different types (UV/IR, smoke, and heat) of detectors are also mounted along the length of the module. The detectors have overlapping fields of view so that a fire anywhere in the bay is seen by two or more detectors. Modules are connected together in series to expand and provide the necessary protection for any aircraft. Connection to the replaceable emergency exit door is made through the use of a flexible hose and cable. The cart remains essentially identical to the first two concepts.

Progress continued on the development of the smart remote terminal, the microprocessor-based sensor system used to receive inputs from multiple sensors and make decisions on false alarm stimuli and real fires. In addition, a design for a smaller, more compact external cart was developed based on Halon 1301 as the suppression agent. A chemically similar but nonfirefighting agent SF6 (sulfur hexafluoride) would be used to demonstrate the suppression system. The cart also has provisions for module storage and RF communication equipment.

As stated in the introduction, a contract modification was made at this point on the effort as a result of a design review meeting held in June 1991. Based on the overall cost, complexity and logistical issues that were being identified with development and implementation of the AFS, the Air Force redirected the scope of the effort. Emphasis was redirected from complex, unproven smart processing of sensor inputs and modules, and the suppression system, towards more conventional means of detecting fires and notification of this information quickly and reliably to the base fire departments. It was deemed more desirable to develop an AFS unit that was smaller, lighter, easily deployed and maintained and without fire suppression capabilities. Commercially available fire detection components and communications equipment were to be assembled in a small, portable self-sufficient unit and functionally tested and evaluated.



LONGITUDINAL SECTION



CROSS SECTION

Figure 5. Dispersion System 2

SECTION III

TASK 2 -- SYSTEM DESIGN AND COMPONENT TESTING

A. TASK 2 DESCRIPTION

The Statement of Work requirement for Task 2 was to produce a functional breadboard design AFS unit which could be tested and evaluated. Test plans for the AFS were to be developed and approved by the project officer prior to the beginning of the test series. A complete set of test results and conclusions would be produced, and a final AFS prototype concept recommended.

The objective was to produce a working model small-scale design for proof of concept. The unit would be tested against real fires and monitored for proper response and notification of the fire to a remote terminal by radio frequency link.

B. TASK 2 ACCOMPLISHMENTS

A breadboard concept of the AFS was designed and assembled using current technology and off-the-shelf components (Figures 6 and 7). Its operation includes the use of photoelectronic smoke detection, heat detection and alarm initiation by manual handle. Fire alarms generated by any of these means would be processed by communication circuitry, and an alarm message would be sent to what would be the fire department, by radio frequency. A successful test series was conducted on the breadboard concept unit.

C. BREADBOARD DESIGN DESCRIPTION

The AFS system is comprised of essentially two separate subsystems. First is the portable detection and transmitting unit, which is the focus of development for this project. The other part is the central transmitting and receiving station (located at base fire departments). This central station is the receiver of all alarm messages generated by remotely located AFS units. The choice of the RF communication system was key to the continuing development of the AFS. Through survey and evaluation of available transmitting and receiving (Tx/Rx) equipment, Monaco Enterprises, Inc. D-500 Plus Advanced Wireless Information Management Alarm Receiving and Reporting System, along with its BT2-3 Building Transceiver would be used as the foundation around which the AFS would be developed. The operation of the D-500 Plus in conjunction with small, potentially portable BT2-3 hardware most closely matched the requirements for AFS communication.

The D-500 Plus includes, but is not limited to a CPU/keyboard, monitor, software, Tx/Rx electronics and an antenna. It can be powered by either AC or DC. Typical operation has the system powered by AC with a DC backup. The system remains active

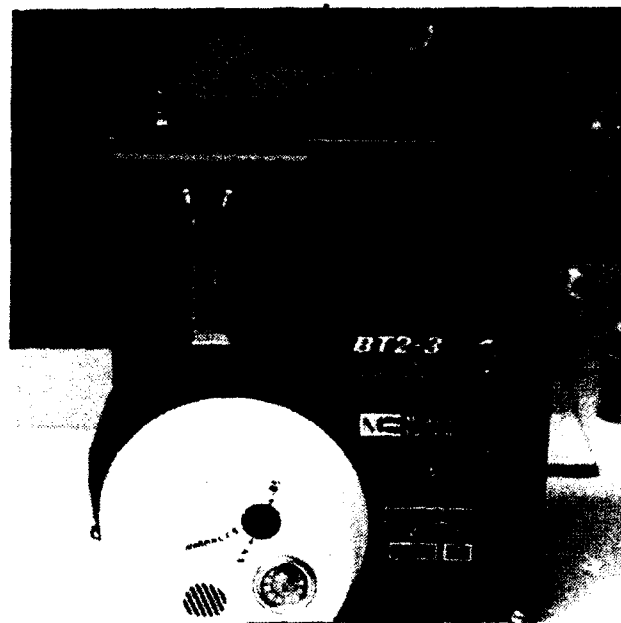


Figure 6. Breadboard Concept AFS

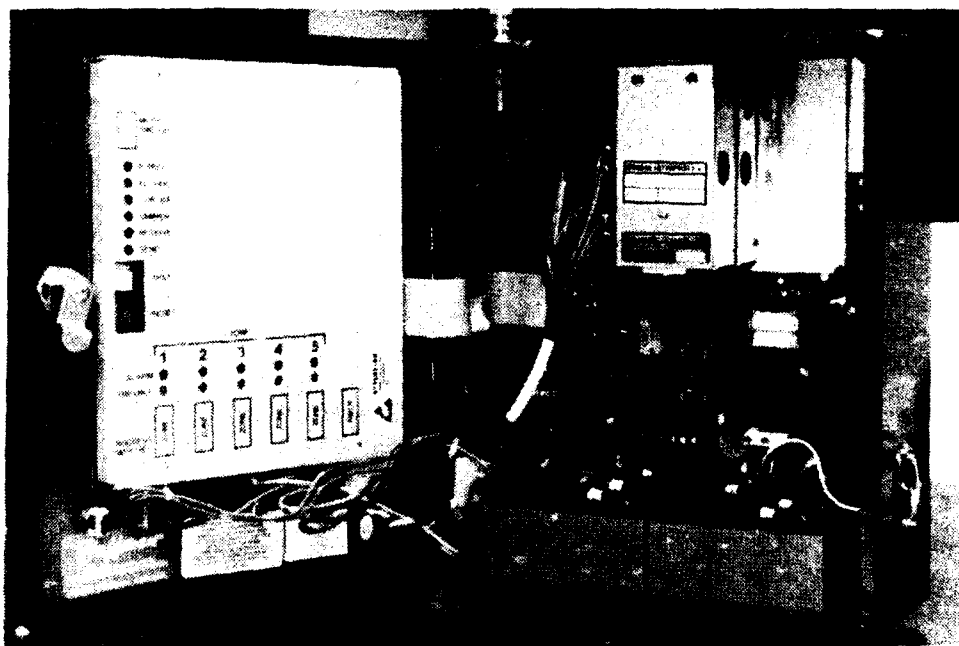


Figure 7. Breadboard Concept AFS -- Internal Components

24 hours a day. It is continuously receptive to alarm messages from any number of remotely located BT2-3 units. The software for the D-500 Plus is specifically designed to communicate with the remote units. The D-500 can be programmed to check the status (battery power, tamper, etc.) periodically of the remote units. When an alarm condition occurs at a remote unit location, an RF signal is sent to the D-500, giving information about the nature of the problem. For instance, information can be displayed on screen as to what has alarmed (smoke or flame detector, etc.), where the emergency is (location or tail number of aircraft), and what action to take. When alarm messages come into the D-500, an audible tone alerts the operator that incoming alarm messages are being displayed on the monitor. The D-500 is referred to as the central Tx/Rx station in this report, as well as the Task 2 and 3 reports (Appendices B and C). Its sole function for this project is to receive and verify incoming alarm messages. No development or evaluation was made concerning the central Tx/Rx. The goals of this effort are to focus on design, testing, evaluation and recommendations for an effective portable fire detecting and notification system -- the AFS remote Tx/Rx. From this point forward, the terms AFS and remote Tx/Rx are synonymous and may be used interchangeably.

As stated earlier, the remote Tx/Rx for this phase is built around a Monaco Enterprises BT2-3 Building Transceiver. The BT2-3 has been modified to include a photoelectric smoke detector with an integrated heat sensor and a horn. Further modifications include a strobe and manual hand pull station on the exterior of the unit. The stand-alone remote Tx/Rx is powered by four internal 12V/1.2AH rechargeable batteries, connected in parallel which should give the unit an operational duration of a minimum of 60 continuous hours without a recharge. The remote Tx/Rx is portable and easy to install. Overall dimensions are 7 in. x 11 in. x 14 in. and weight is 20 lbs. The normal system antenna is the BSA-1 VHF Omnidirectional Antenna Assembly which is located at both the remote and the central Tx/Rx units. This system transmits at a frequency of 138.925 Mhz. The photoelectric smoke detector has a nominal sensitivity of 2.5 percent per foot obscuration. The thermal sensor was selected with an initial level of 135°F and the piezo horn had an audio level of 90 dB.

Smoke, heat, and manual pull inputs are connected to zone addresses inside the BT2-3. The zones are uniquely addressable input locations inside the BT2-3 that can give specific information about the nature of the alarm. Scanning of zones occurs at the rate of about twice per second. There are five zones available, two of which are used. One is used for smoke/heat, and the other is used for manual pull.

D. BREADBOARD AFS SYSTEM TESTING

The performance of the AFS system was demonstrated through a series of various functional tests. A test plan was submitted to and approved by the project officer which allowed objective evaluation, and to determine if the system meets the requirements as set forth in the Statement of Work.

The test series is composed of four types of tests: (1) 60-Hour Operational Test, (2) Manual Pull Station Test, (3) Heat Test, and (4) Live Test. Each type of test was repeated to show system repeatability. The live testing can be further divided into smoke and fire tests.

The 60-Hour, Manual Pull and Heat tests were conducted at the Applied Research Associates Lakewood, Colorado laboratory. The live tests were carried out at ARA's remote test site which is approximately 30 miles east of Denver, Colorado. These tests were conducted at this location for two reasons. First, a significant distance was needed between the test location and the location of local owners of the same radio frequency (138.925 Mhz). To further minimize interference, all tests were run using a 50-ohm dummy load as the antenna in an effort to reduce radiated signal strength. The second reason relates to safety. The potentially dangerous nature of fire testing cannot be done at the scale required in laboratory conditions. ARA's outdoor test site is suited for hazardous testing.

A structure in which the tests were conducted was built at the test site, with a geometry resembling the cross-sectional shape of a C-130 aircraft. The length, however, is approximately one-third (16 feet) that of the aircraft (Figures 8 and 9).

A copy of the Task 2 Test Plan detailing the objectives and procedures of each test can be found in Appendix B.

1. Instrumentation

Instrumentation used to gather and record data for the Task 2 Test Series included:

- smoke density/obscuration detectors,
- thermocouples,
- duration trigger box,
- stopwatch,
- digital recorders,
- video,
- black and white still photography,
- IR photography,
- voltmeters,
- portable radio scanner.

For the Smoke and Live Fire tests, smoke density was measured and converted into percent obscuration per foot. This is the standard to indicate sensitivity of commercial smoke detectors (reference: UL 268 "Smoke Detectors for Fire Protective Signaling Systems"). The main components of a smoke obscuration detector are a lamp with a power supply and a photocell with signal conditioning. These components are mounted to a structure which separates the lamp and photocell by exactly 5 feet. During operation,

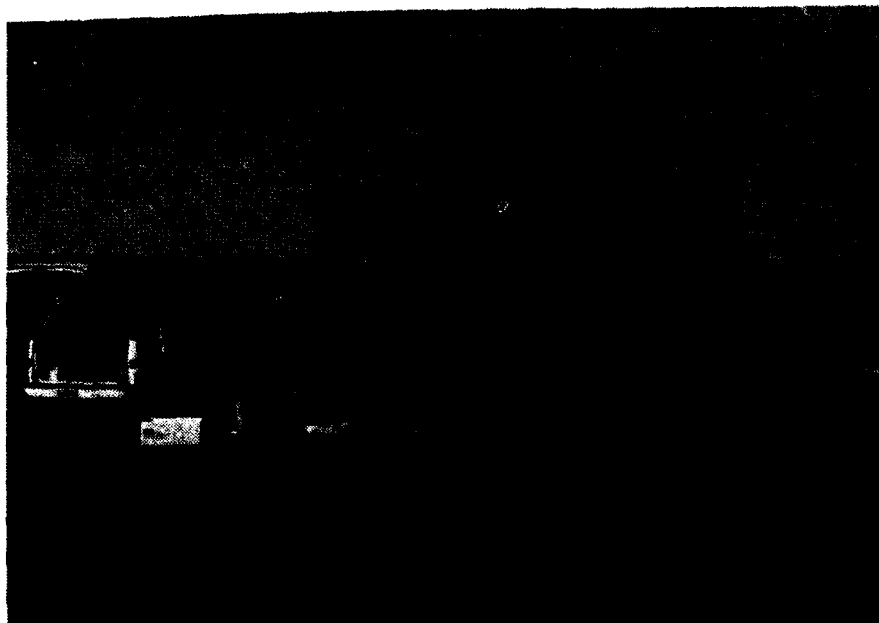


Figure 8. Side View of Structure with Instrumentation Van

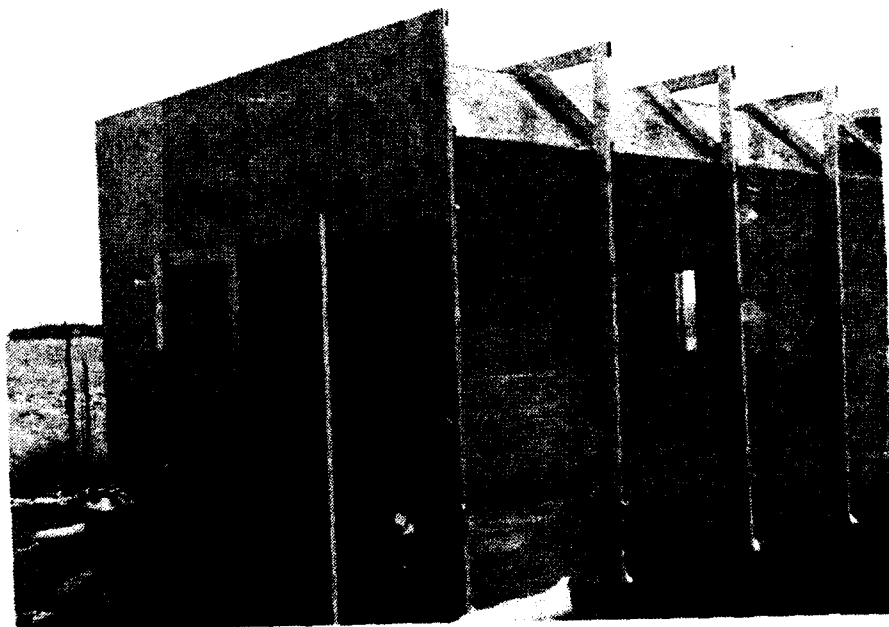


Figure 9. Live Smoke/Fire Test Structure

with the lamp on, an amperage is created in the photocell and converted to an analog voltage output by the signal conditioner.

As smoke passes between the lamp and photocell, the amperage created by the photocell decreases. At any distance, the percent obscuration per foot can be calculated by:

$$S.O. = \left[1 - \left(\frac{V_F}{V_I} \right)^{\frac{1}{D}} \right] 100$$

where: S.O. is percent obscuration per foot,
V_F is voltage reading with smoke,
V_I is voltage reading in clean air,
D is distance between lamp and photocell.

Smoke obscuration was measured at a point approximately 12 inches from the AFS smoke detector, and recorded output is the average obscuration (density) over 5 feet.

Fast-response thermocouples were used to monitor temperature during the Heat and Live Fire tests. The current generated by the thermocouple was conditioned by a digital pyrometer. The pyrometer used the thermocouple output, referenced it to 32°F, linearized and amplified the signal, then output a 0 to 5 volt DC signal. The pyrometer also has a four-digit display to observe the temperature in real time. For the live fire tests, temperature measurements were taken near the fire source, at the AFS, and a point midway in between.

Time reference for the smoke and live fire tests was generated by a hand-held, 9-volt trigger box. As the smoke began or the fire was set, the box was manually activated. This created a time reference for the recorders and also initiated recording of smoke obscuration and temperature signals. When the alarm was generated by the AFS unit, the trigger was deactivated, which sent another time reference signal to the recorders. A hand-held stopwatch was used as a back-up and during manual and heat testing.

Recording of data during the Smoke and Live Fire tests was achieved by stand-alone Digistar II digital recorders. Manually monitoring voltmeters and the digital pyrometers, and documenting values at critical times were also performed.

Photodocumentation of the tests was accomplished with a color VHS video camera, a 35 mm SLR camera with black and white film, and 35 mm photography using infrared film and filters, during the Live Fire tests. The tripod-mounted infrared photography was focused in the direction of the AFS unit during these tests. Results of

the IR photography indicate IR levels so low in the vicinity of the AFS unit that no useful information was collected by this method.

As a backup, a portable radio scanner preset to 138.925 Mhz was used to pick up alarm signals in the event the central Tx/Rx did not.

2. Test Results

A total of 25 separate functional performance tests were successfully conducted on the breadboard design AFS system during November 1991. Of the 25, three were 60-hour duration tests, 2 were manual alarm tests, 5 were heat tests, and 15 were live tests. The 15 live tests were comprised of 4 live fire tests, and 11 smoke tests using commercial smoke generators as the source.

The 60-hour duration test was conducted successfully three times to verify that the AFS could operate (continuously detect then transmit when necessary) for up to 60 continuous hours without a recharge. Two tests were run at 72°F conditions and one at 33°F. Although the "low batt" LED was illuminated at each 60-hour mark (battery voltage less than 10 VDC), radio transmissions were still possible.

Manual alarm tests were conducted to demonstrate correct performance of the manual pull station modification onto the AFS. Each pull of the alarm handle produced the correct alarm message at the central Tx/Rx.

A fixed temperature heat sensor rated at 135°F was integrated with the AFS smoke detector. Five separate heat only tests were run to verify the performance of this sensor. Two of the tests used flame as the heat source, and the remaining three used a portable radiant electric heater as the source. The AFS did go into alarm each test and transmit the proper alarm message to the central Tx/Rx. However, the average temperature at which alarm was initiated was 176°F.

Smoke and live fire testing was the balance of the Task 2 test series. Multiple tests were run, changing the height of the AFS to determine where the AFS was most effective. The four heights were at floor level, 3 feet, 6 feet and ceiling level (9 1/2 feet). The smoke/fire source was always in the same location, on the floor against the opposite wall. Layout of the equipment in the test structure during these tests is shown in Figure 10.

The first 11 tests were smoke tests using the commercially produced smoke generators as the source. Based on analysis of all of this series test results, it was concluded that the smoke produced by these generators could not be generalized to that of a real fire. Response times were much slower. However, these tests were beneficial in demonstrating overall AFS system performance and repeatability. The smoke detector sensed and generated an alarm condition successfully for each test, and the central station received the correct alarm messages. These tests also confirmed that the AFS (or at least the smoke detector) is most effective when placed higher in the structure.

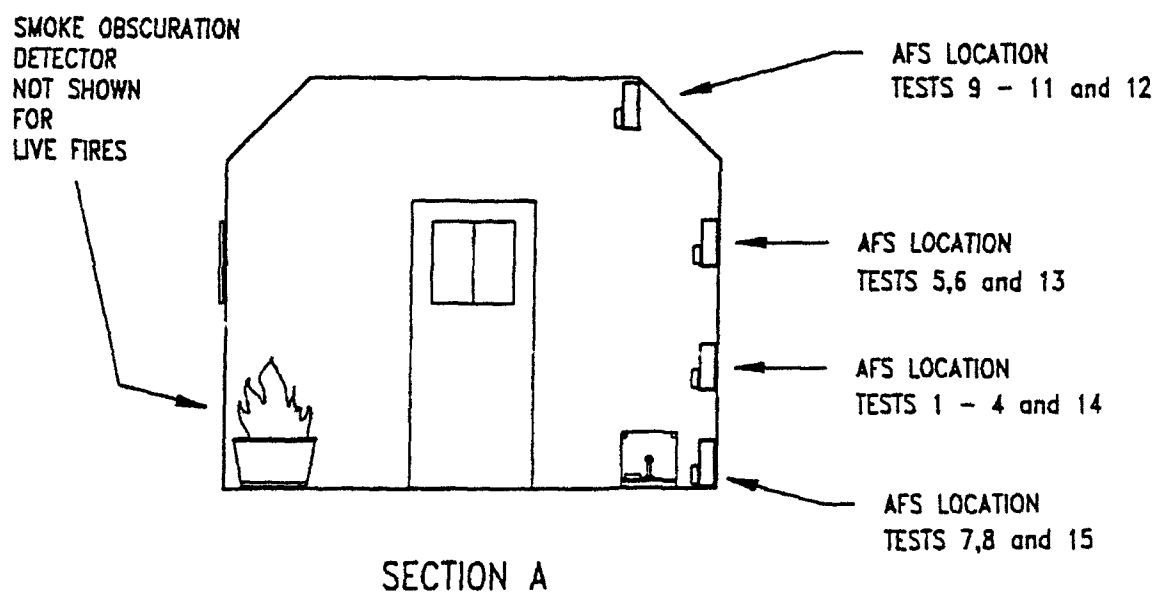
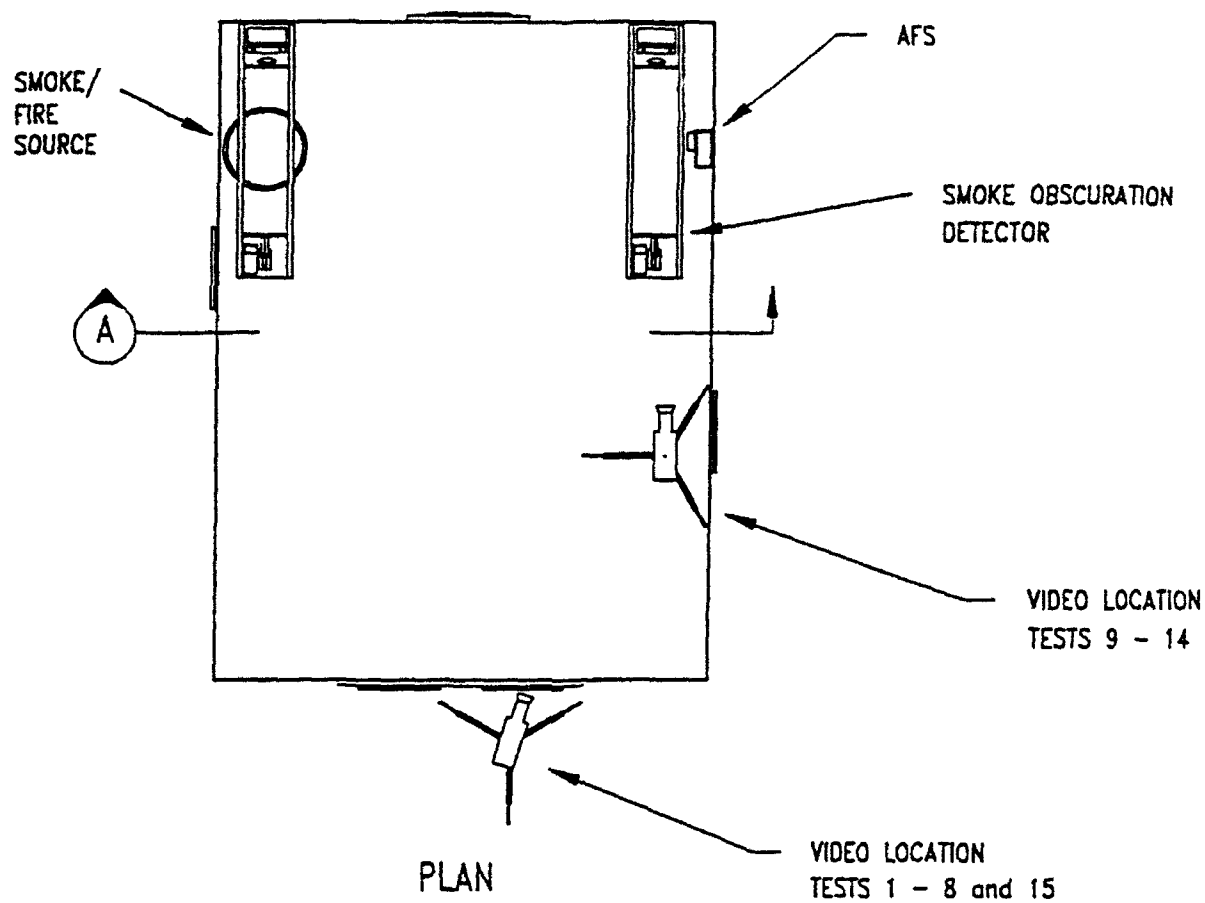


Figure 10. Equipment Layout in Structure

Sensors detected smoke almost five times quicker when the AFS was at ceiling height as opposed to being at floor level.

The fuel source for live fire testing consisted of materials that would simulate materials which could be found in an aircraft cargo bay. Strips of fabric padding had kerosene and motor oil poured over them. As the mixture was lit, the kerosene readily ignited the padding, producing flame while the burning oil produced smoke. Identical quantities of each material were used for all live fire tests.

In addition to the timing and smoke-obscuration instrumentation used during the previous smoke testing, the three separate temperature measurements were also recorded. Only very small temperature increases were seen on the middle temperature sensor. Temperature records for the sensor near the fire source ranged between 98°F and 441°F, depending on whether the flames came into contact with the thermocouple. Average temperature of the environment near the fire was 171°F. The most applicable temperature data were gathered near the AFS. These are of interest in determining which detector on the AFS (smoke or heat) triggered the alarm.

The AFS performed properly during the live fire tests. As expected, the higher up it was placed, the quicker the response time. The central station received the correct alarm message each time. Based on the temperature records, it was the smoke detector that initiated each alarm. A summary of live fire tests is in Table 2. Graphical data records for obscuration and temperature vs time for each test can be found in Figures 11 through 18.

TABLE 2. SUMMARY OF TEST 1 LIVE FIRE TESTING

<u>Test No.</u>	<u>AFS Height Above Floor</u>	<u>Test Duration to Alarm</u>	<u>Temperature Increase at AFS From - To</u>		<u>Measured Smoke Obscuration</u>
12	9 1/2 ft.*	13 sec.	42°F	82°F	2.6% per ft.
13	6 ft.	23 sec	42°F	78°F	1.5% per ft.
14	3 ft.	72 sec	42°F	63°F	3.8% per ft.
15	floor level	137 sec.	42°F	57°F	6.1% per ft.

* ceiling height

AIRCRAFT FIRE SENTRY

(TEST 12 -- FIRE 1, AFS @ 9.5' a.f.l.)

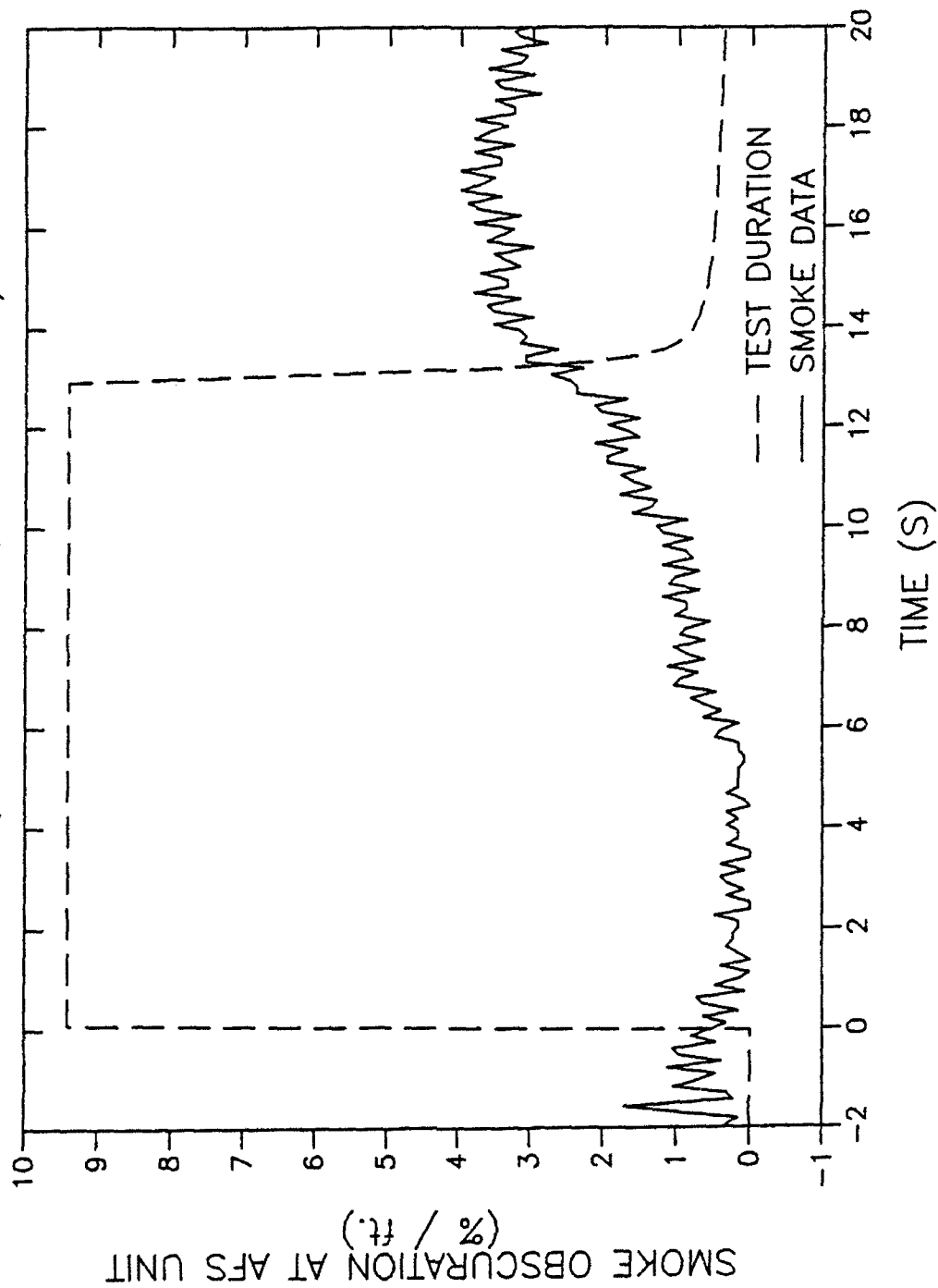


Figure 11. Smoke Obscuration -- Test 12

AIRCRAFT FIRE SENTRY

(TEST 12 -- FIRE 1, AFS @ 9.5' a.f.l.)

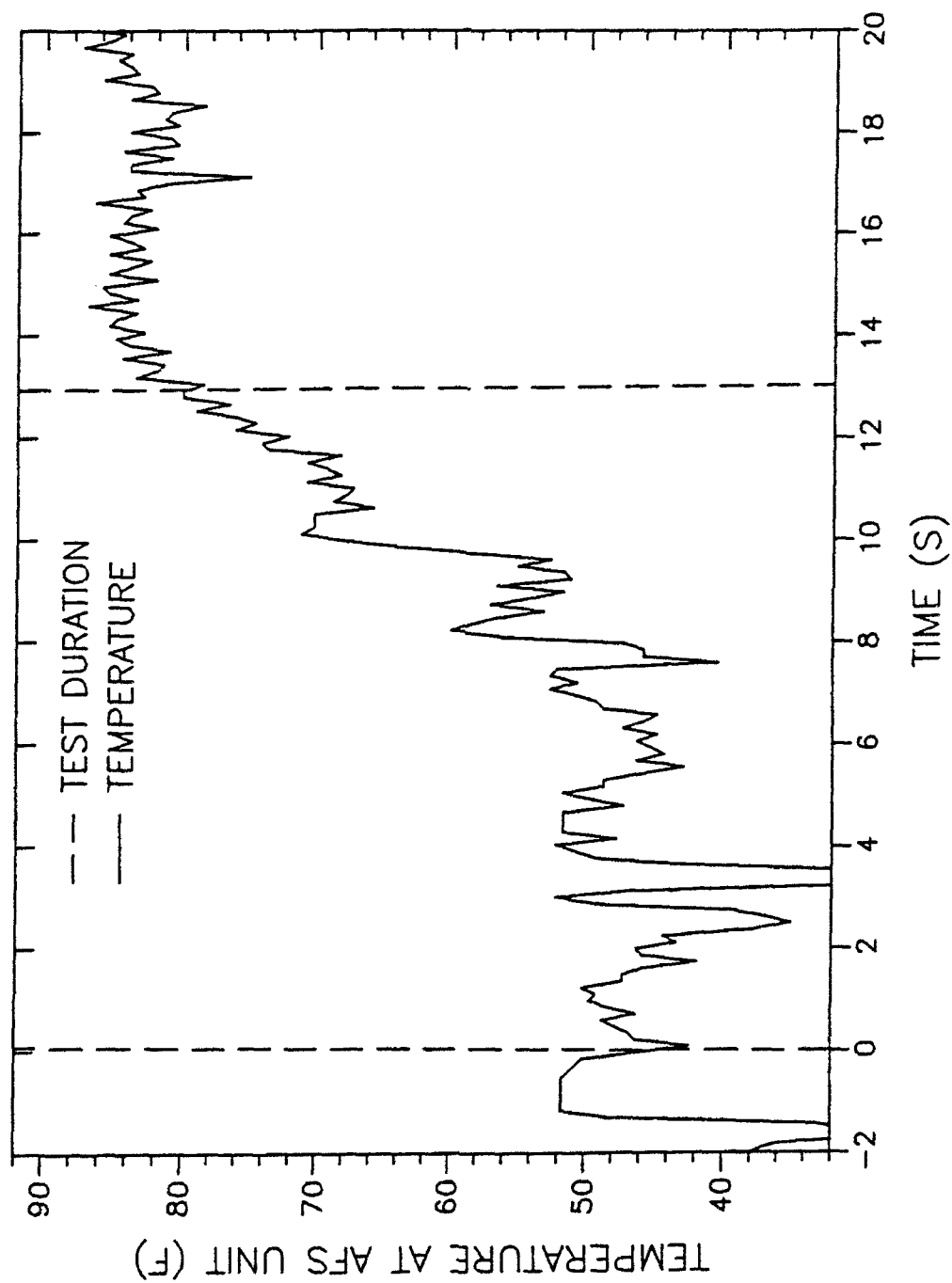


Figure 12. Temperature -- Test 12

AIRCRAFT FIRE SENTRY

(TEST 13 -- FIRE 2 , AFS @ 6' a.f.l.)

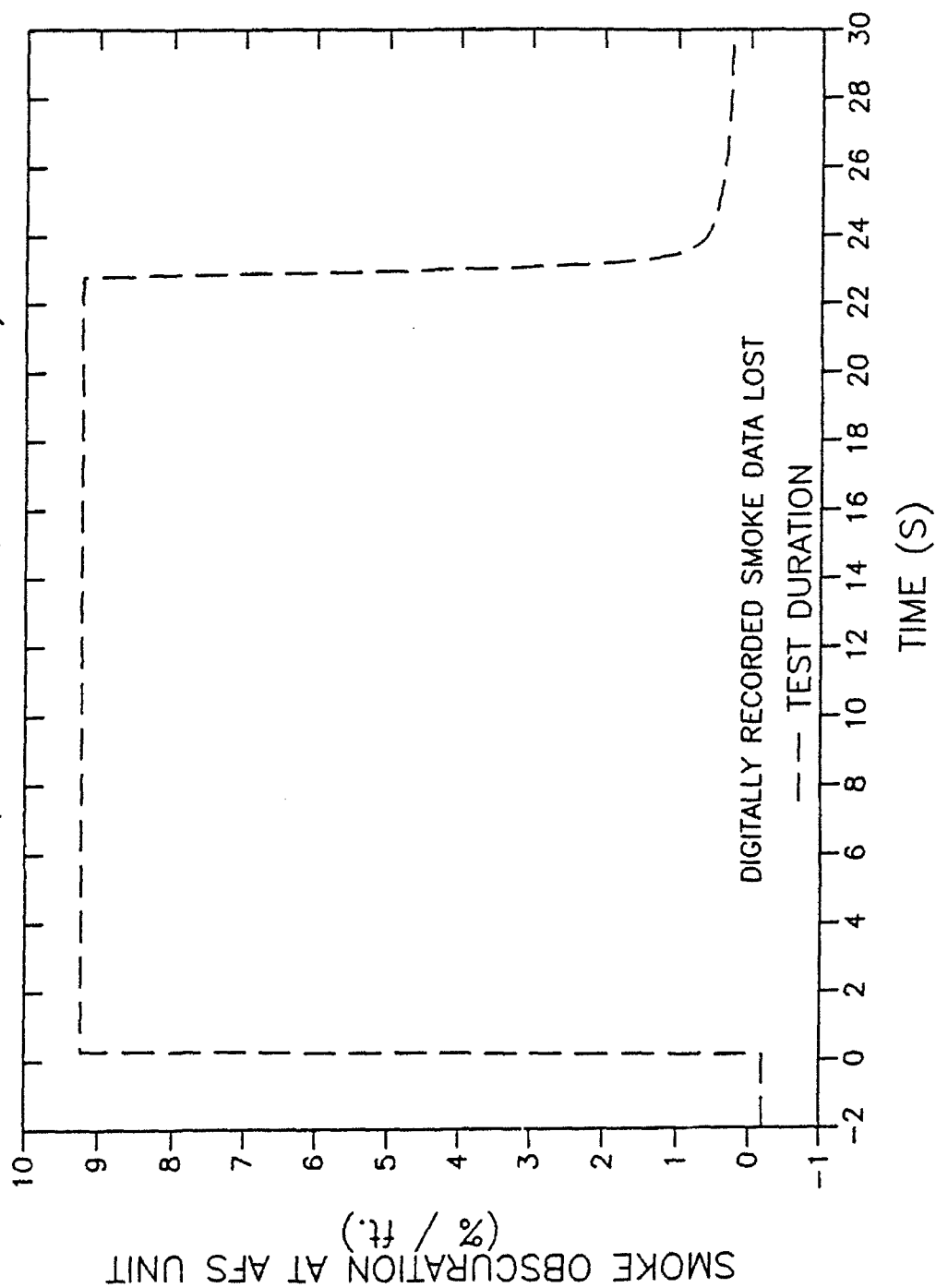


Figure 13. Smoke Obscuration -- Test 13

AIRCRAFT FIRE SENTRY

(TEST 13 - FIRE 2, AFS @ 6' a.f.l.)

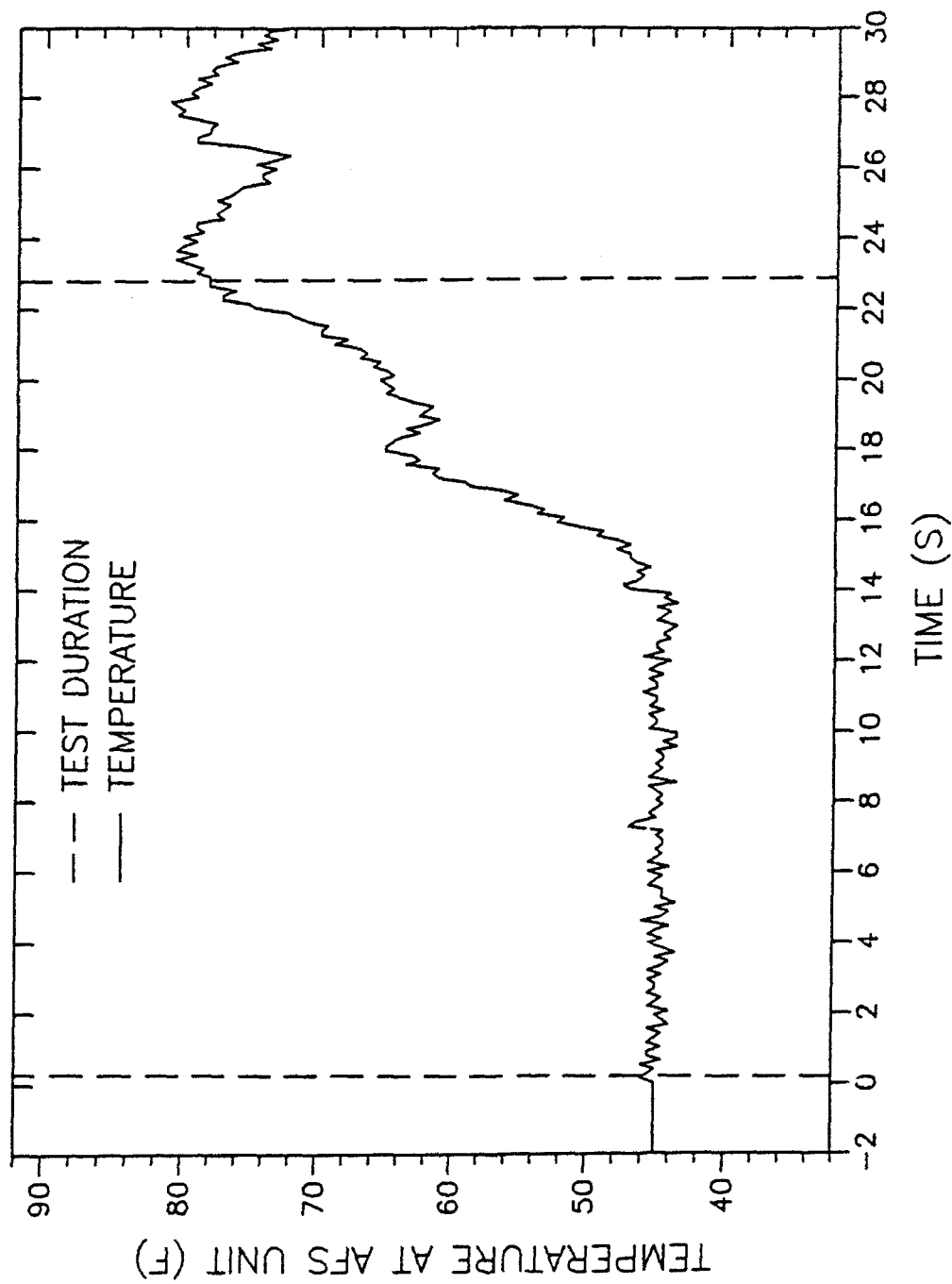


Figure 14. Temperature -- Test 13

AIRCRAFT FIRE SENTRY

(TEST 14 - FIRE 3, AFS @ 3' a.f.l.)

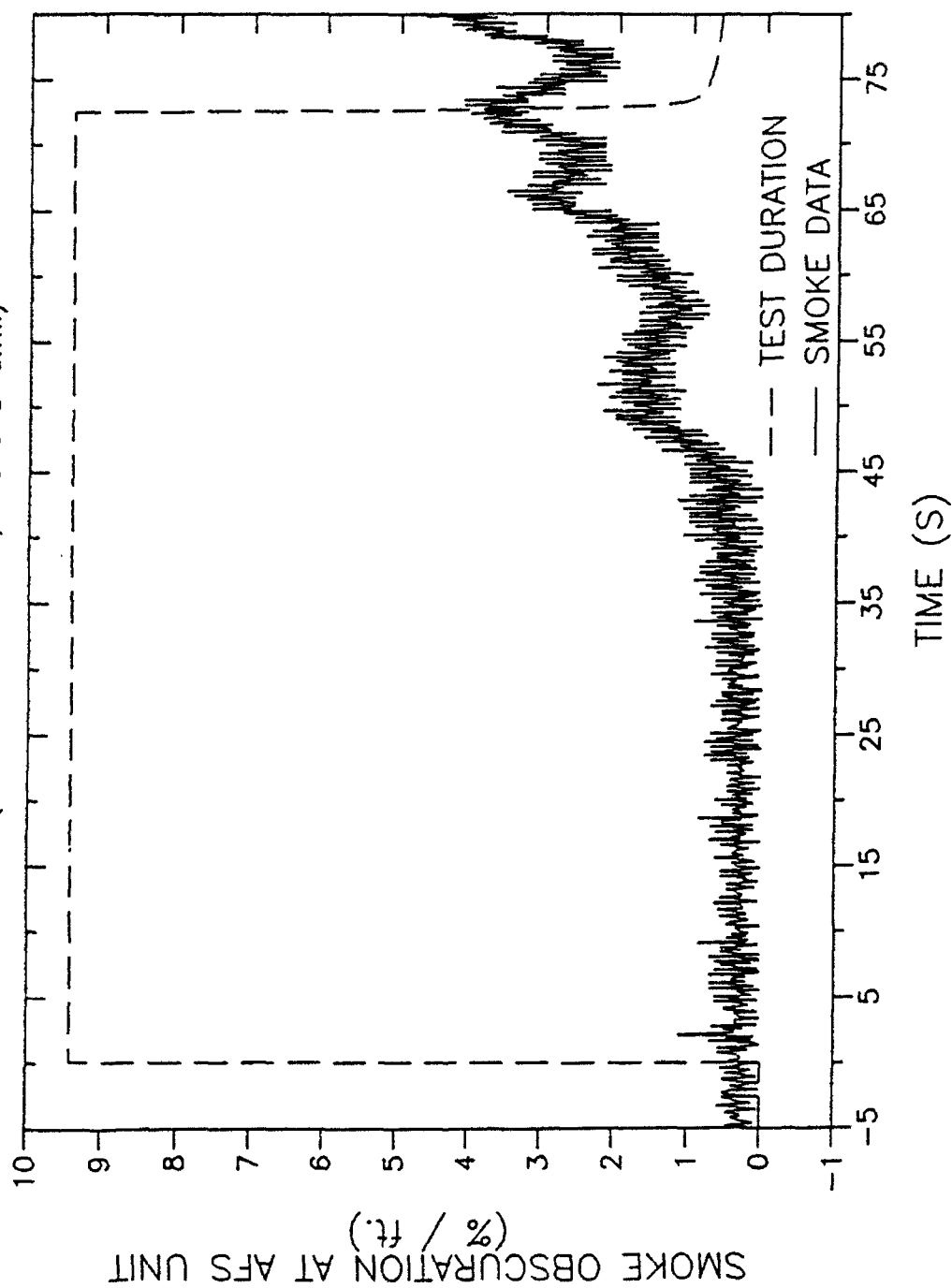


Figure 15. Smoke Obscuration -- Test 14

AIRCRAFT FIRE SENTRY

(TEST 14 - FIRE 3, AFS @ 3' a.f.l.)

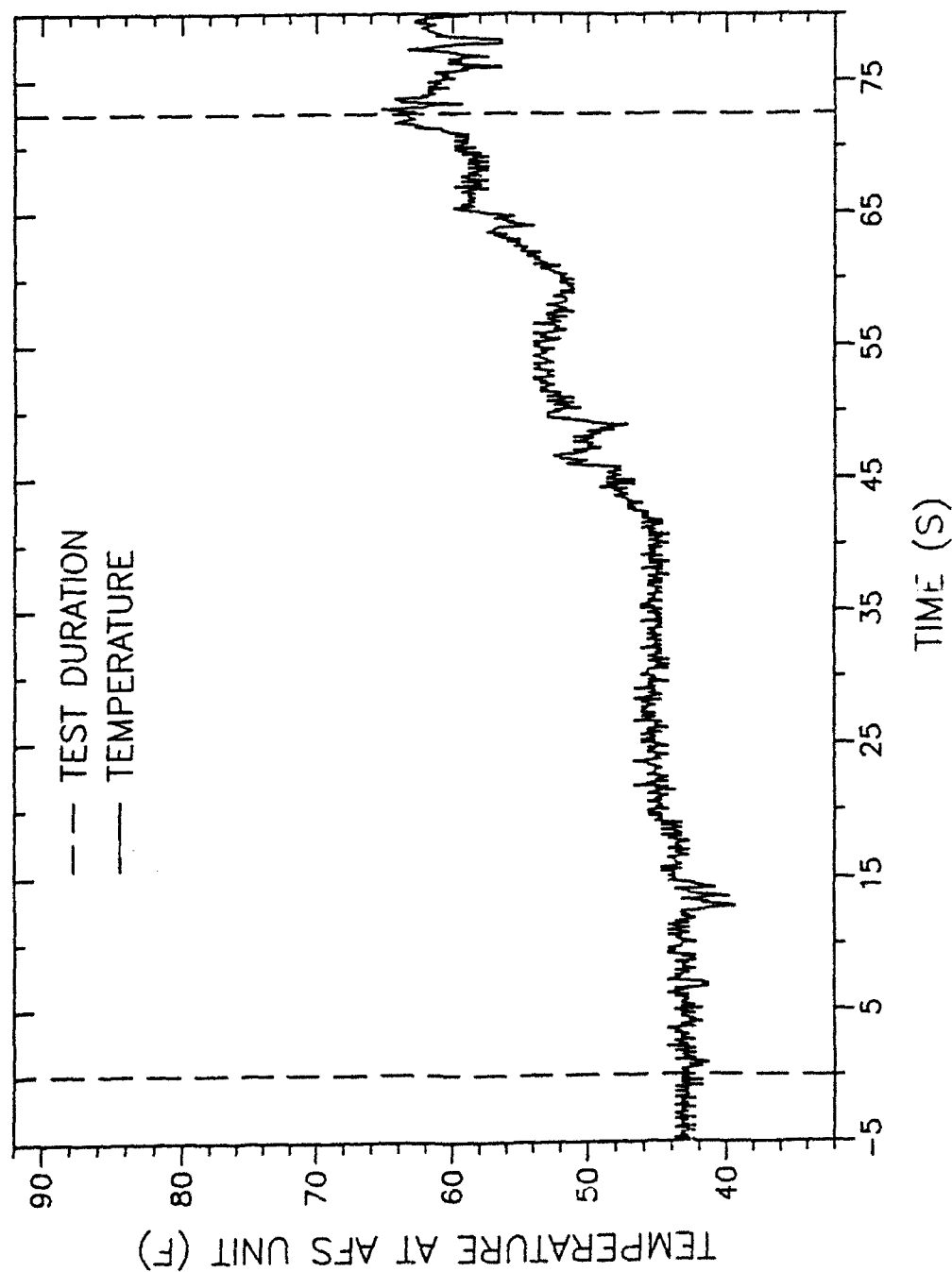


Figure 16. Temperature -- Test 14

AIRCRAFT FIRE SENTRY

(TEST 15 - FIRE 4, AFS @ 0' a.f.l.)

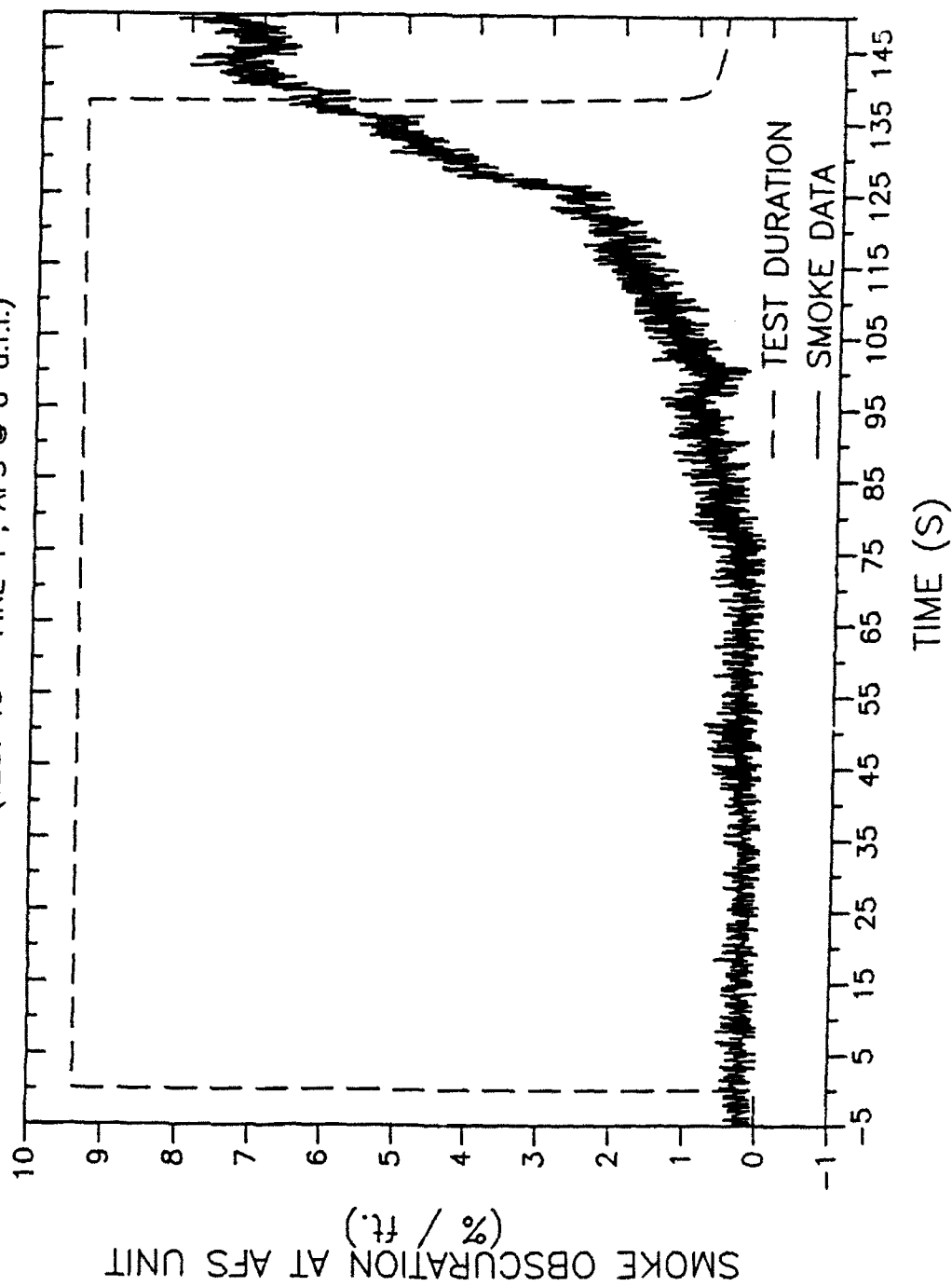


Figure 17. Smoke Obscuration -- Test 15

AIRCRAFT FIRE SENTRY

(TEST 15 - FIRE 4, AFS @ 0' a.f.l.)

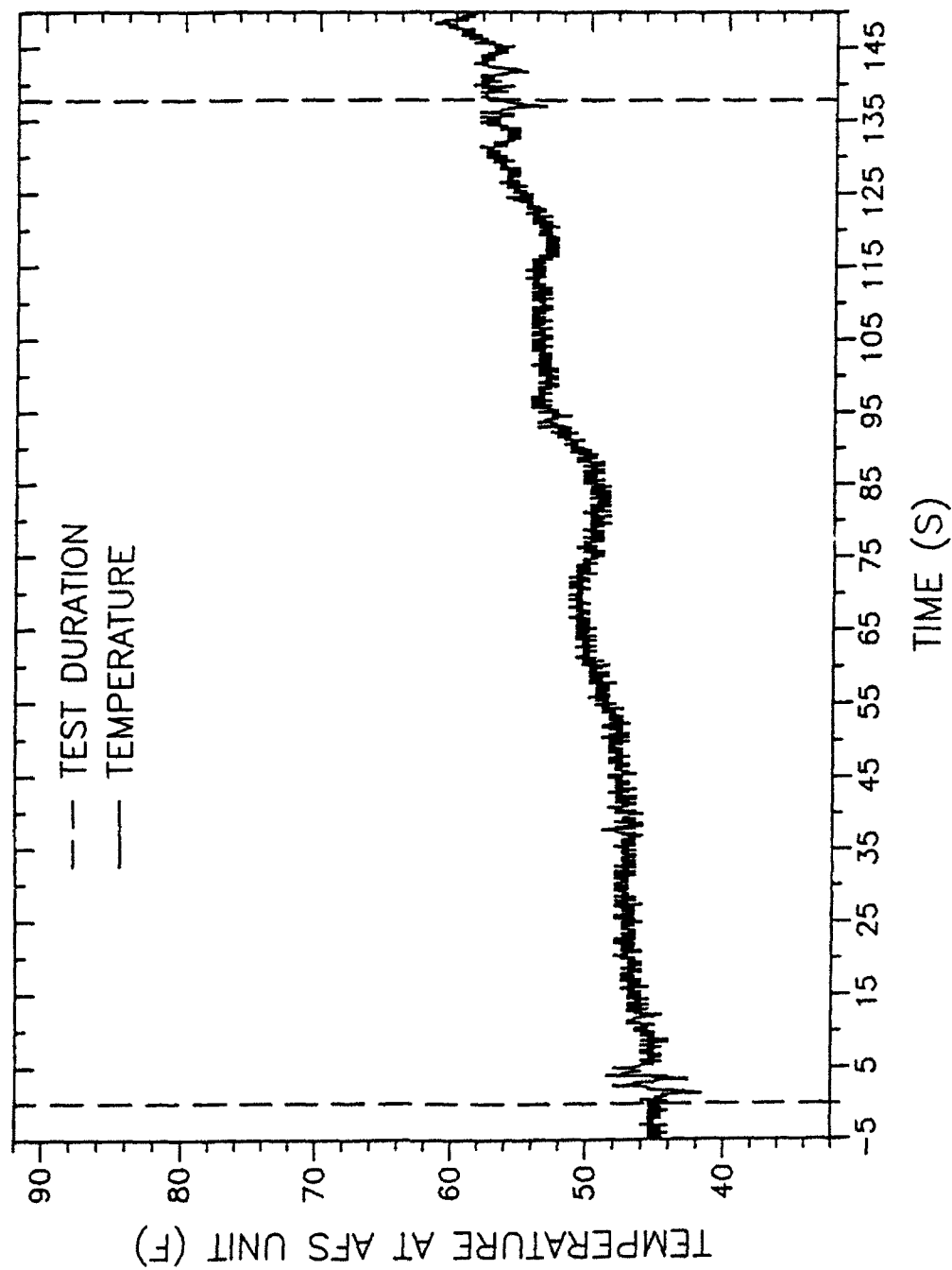


Figure 18. Temperature -- Test 15

E. CONCLUSIONS

This design of the current AFS concept hardware has passed all tests required to demonstrate functional operation. The remote Tx/Rx never failed to detect fire or smoke stimuli and notify the central Tx/Rx.

Based on temperature records, the smoke sensor triggered the alarm in each case for the live fires. The fixed temperature heat sensor triggered at approximately thirty percent higher than its rated value based on the heat tests. The strobe and audible horn were active during each alarm; however, the strobe would often become obscured during the smoke tests and unable to see at a distance of 12 feet. Response times to stimulus improved the higher the AFS was placed in the test structure. This verifies efficiency of smoke alarms placed at ceiling height. At ceiling height, however, personnel cannot reach the manual pull handle if necessary.

Once fully charged, the AFS can operate continuously for 60 hours.

F. RECOMMENDATIONS

Future AFS designs would benefit from the additional technical and operational recommendations. All of the comments pertain to the remote Tx/Rx unit and were formulated as a direct result of the test series.

The AFS prototype should have the same operating principles as the Task 2 model. It will transmit alarm messages to a central Tx/Rx by a VHF radio frequency signal as a result of any of its detectors sensing a smoke or fire condition. An audible alarm will sound and a strobe will flash on the aircraft in trouble.

There are two main issues which are the foundation of the majority of the changes for the prototype. First, the ideal location for the remote unit is as high as possible inside the cargo bay. In all cases, this puts the unit out of normal reach which makes it difficult to monitor or access during installation or in the event of an emergency. A solution is to place the prototype unit between floor level and 6.5 feet, and sample the environment near the ceiling by means of an extended, tethered or remote device. Options for this are presented in a features list below. The second issue that substantially reconfigures the remote unit is the location of the strobe and horn. It will be more effective to have these two items located outside the aircraft along with the antenna. This will aid the fire department or flight line personnel in finding the aircraft on fire and insure unobstructed VHF communications.

The exterior of the box should be free from as many protruding components as possible. This will reduce the possibility of damage to these components during handling.

The overall size, shape, and weight of the prototype may increase from the breadboard design due to the new configuration of components associated with the remote unit.

The recommended features of the prototype AFS include:

- an appropriately sized, environmentally tight enclosure,
- similar electronics boards and transmitter/receiver modules as the small scale design (BT2-3),
- same operating frequency as small scale design (Tyndall =138.925 Mhz),
- modular interior construction. Easy access removal and replacement of components. Possible card cage/edge connector arrangement,
- 10- by 10- by 4-inch space allocated for machine vision flame detection system. Although machine vision is still under development and will not be installed, a UV flame detector will be used as a simulator. Cut one hole in a selected side of the enclosure and install an appropriate glass lens,
- a manual pull station,
- an exterior mounted master switch with a complete unit reset function,
- three exterior LED's to monitor: a) power on/off, b) low battery, and c) tamper/trouble,
- exterior switches for unit addressing,
- an AC recharging receptacle,
- 60-hour back-up battery capability with the possibility of a removable/rechargeable battery power pack,
- hook/strap type hardware for mounting the unit inside the aircraft,
- horn, strobe, and antenna assembly that will be easily mounted on the exterior of the aircraft and connected to the remote unit with cable (pre-wired plug in assemblies),
- smoke detection capability to sample air from one to fifteen feet from the remote unit. Options may include: a) "beam" detector system utilizing a telescoping assembly that can extend the emitter or receiver away from the box, b) separate photoelectric or fixed separation beam detector which could be hung at any height and connected to the remote unit with cable (pre-wired plug in assemblies), or RF linked,
- a compatible storage box for the remote assembly's loose components (i.e., smoke detector, horn/strobe, antenna, cabling).

All hardware inside the BT2-3 (or similar) unit should be secured so that nothing rattles or moves during handling. Commercial equipment to be used must have a standard environmental operating range of 32°F to 100°F.

SECTION IV

TASK 3 -- PROTOTYPE DEVELOPMENT, CONSTRUCTION, TESTING AND EVALUATION

A. TASK 3 DESCRIPTION

The Statement of Work requirements for Task 3 were to produce a prototype AFS unit based on the results and recommendations from the previous task, and approval by the project officer. The unit would be tested for function and reliability, and tested in an actual aircraft. Test plans were submitted and approved by the project officer.

B. TASK 3 ACCOMPLISHMENTS

A final design review meeting was held at ARA in February 1992 to discuss the configuration of the prototype. The prototype was assembled by Monaco Enterprises, Inc. and delivered to ARA for testing in July 1992. Prior to this delivery, representatives from the Air Force, ARA and Monaco Enterprises participated in a performance demonstration of the AFS at Fairchild AFB. The unit was deployed on-board a C-135 tanker and established its reliability for notification of fire emergencies to the base fire department. Performance testing for function and reliability was conducted at the ARA remote test facility. Following the test series, a report was written summarizing the entire Task 3 effort. This detailed report can be found as Appendix C in this report.

C. PROTOTYPE DESIGN DESCRIPTION

The prototype AFS unit is a self-powered, portable fire sensing and alarm reporting system (Figure 19). The unit is carried on-board and set up in the cargo bay of large aircraft. The set-up involves placing the wireless smoke detector(s) in the desired locations inside the aircraft, attaching the system antennas and cables to the unit, and hanging the strobe/siren assembly outside. One external switch powers up the AFS, and at this time it is actively sensing fire or smoke conditions and able to report an alarm to the base fire department over a preset radio frequency (RF).

The types of detectors on the prototype are smoke and flame. The smoke detector(s) are battery powered photoelectronic smoke alarms with a built-in wireless transmitter. The sensitivity of the detector is 3.1% smoke obscuration per foot $\pm 0.5\%$. The operating frequency is 303.875 Mhz. The transmitter will produce three-second coded RF transmissions every 30 seconds as long as an alarm condition exists. It also has an internal horn (85 dB at 10 ft). The detector is six inches in diameter and weighs 12 ounces. Two of these wireless smoke detectors are provided with the prototype AFS.

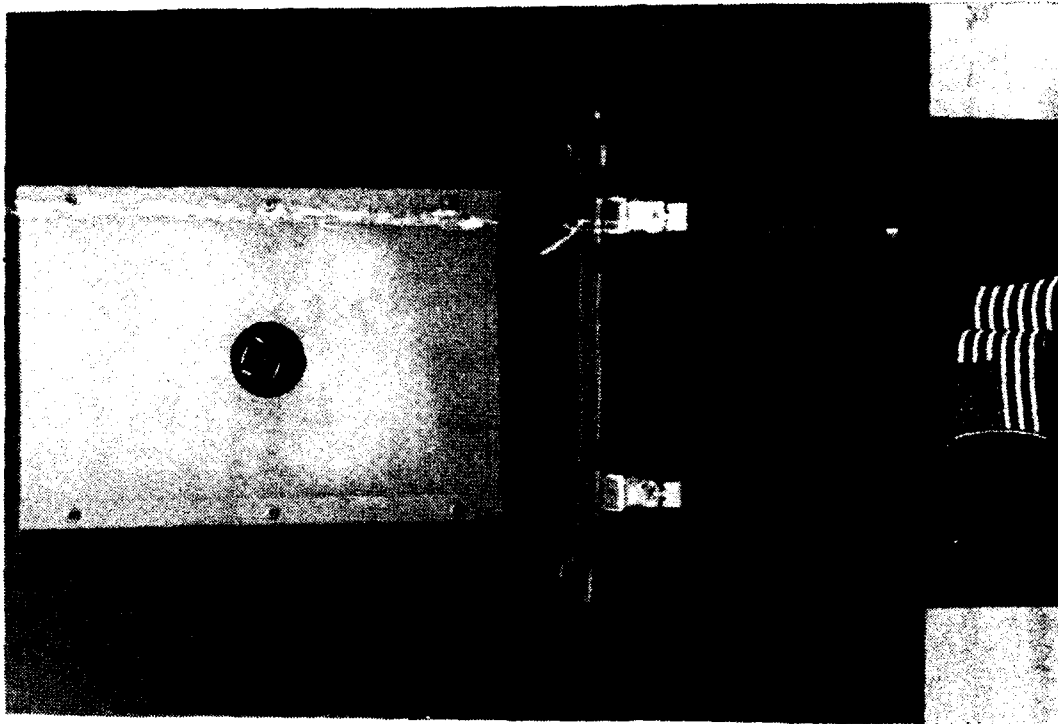


Figure 20. Prototype AFS UV Sensor

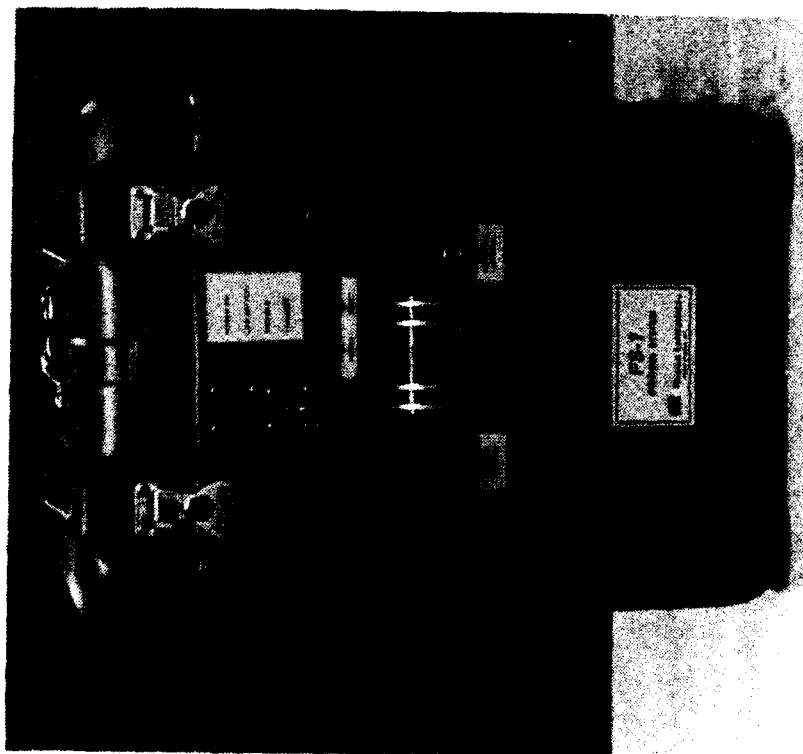


Figure 19. Prototype Aircraft Fire Sentry Unit

The other type of detector is a standard ultraviolet (UV) flame detector. This unit operates on 12 VDC and has a 32° cone of vision with respect to its placement inside the enclosure. There is only one of these flame detectors used on the prototype and it is situated so that it looks out the backside of the prototype box (Figure 20). Normal response time is 3 seconds at 12 feet for a 12-inch diameter hydrocarbon fire. This UV detector is intended to illustrate that the AFS has flame detection capabilities. It is envisioned that an actual AFS would have flame detection capabilities in four separate directions, and that more advanced technology, such as the Machine Vision system, which is currently under development, could possibly be used. The advantage of using some system like Machine Vision is that it provides state-of-the-art flame detection with a very low to zero false-alarm performance. The system would be placed in the AFS so that it would look out all four sides and have virtually a 360° cone of vision.

The prototype's sensors (or detectors) differ from those of the previous breadboard small scale design AFS in three ways. First, there is no heat-detection capability on the prototype. Task 2 testing on the small scale system indicated that heat levels were not rising high enough to trigger an alarm before another sensor (smoke) initiated an alarm. Therefore, it was concluded that heat sensors would generally be an added expense to the prototype configuration and not too useful. In addition, the heat sensor tested would alarm at an average of 176°F, while rated at 135°F. The second major difference is that the prototype has flame detection, while the previous design did not. This capability is seen as a must, and a perfect complement to smoke detection for an effective well-balanced system. The third difference is that the smoke detector(s) for the prototype are remote (that is, not hardwired or attached) to the AFS enclosure which contains the transmitters, electronics, etc. This is seen as an advantage in that the prototype unit (with flame detection) could be placed at a suitable location mid-fuselage while the wireless smoke detector(s) can be placed at multiple locations for quicker, more efficient response to a smoke source. Both the prototype and small-scale (breadboard) AFS concepts have included a manual pull station to enable personnel to initiate an alarm at anytime.

Fundamental to the success of the AFS is the understanding of the communication network on which it operates. The prototype AFS assembly is essentially a remote transmitting and receiving station of radio frequency signals.

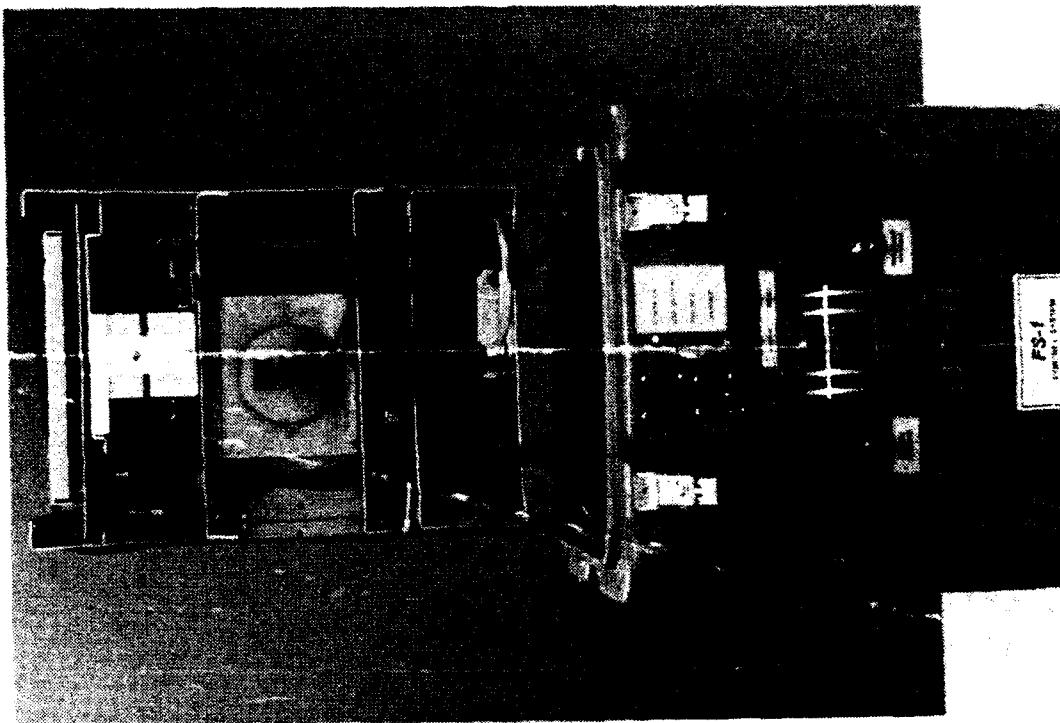
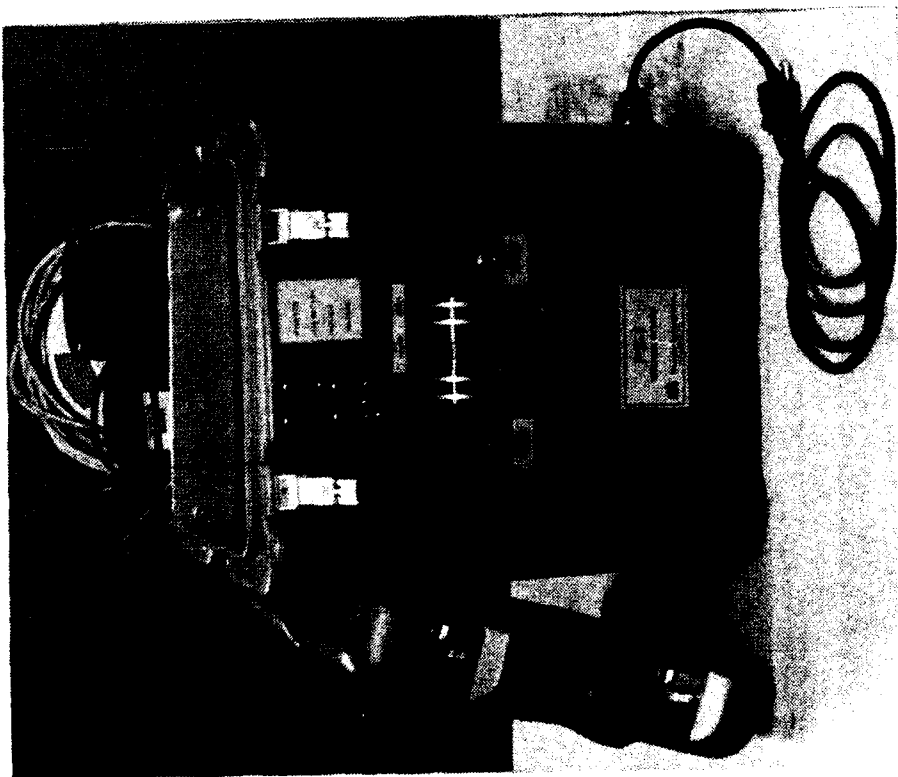
Base fire departments of most U.S. Air Force air bases have central transmitting/receiving stations which are being monitored by personnel for hazards anywhere on base. As soon as an AFS detector triggers, an alarm signal is sent to the AFS unit and an alarm condition occurs at that location. As the electronics in the AFS receive the alarm from the detector, another signal is then generated which notifies the base fire department of the type and location of the problem. The messages received at the fire station can be what went into alarm (smoke detector, manual pull station, etc.) and where to send help (tail number of plane, location on the ramp, etc.). The result of a properly operating and set up AFS system is efficient, automatic fire detection and notification.

The hardware used for the Tx/Rx communications between the AFS prototype and the central station is the Monaco Enterprises, Inc. BT2-3 Building Transceiver and the D-500 Plus Advanced Wireless Information Management Alarm Receiving and Reporting System, respectively. The BT2-3 has five zones, each being responsible for receiving the input of one sensor. The BT2-3 scans these zones for alarm conditions twice per second. On the prototype, Zone 1 is for system trouble or tamper, Zone 2 monitors the manual pull station, Zone 3 monitors the UV flame detector, and Zones 4 and 5 are for the two smoke detectors. The BT2-3 uses a rechargeable 12 VDC battery for power. At the central station, the D-500 Plus is AC or DC powered and computer based. Its software is specifically designed to monitor the remote BT2-3 units. Although the D-500 Plus is integral to the whole AFS concept, the focus of AFS prototype design efforts is on developing an efficient, portable remote unit. Operating radio frequency for the AFS is 138.925 Mhz.

The majority of components are housed in a high-impact plastic, environmentally sealed enclosure approximately 14 inches wide by 14 inches long by 20 inches high. Total weight of the assembly is 39 pounds. It has three handles, one on each side, and one on the top for carrying purposes. On the front of the unit are the power and system reset switches along with four LED's indicating power on, low battery, trouble and transmit. In the prototype, only the power on LED is functional. The remaining three were never wired into the system before shipping. Four connectors are provided on the front. Four different types of quick connects prevent a wrong hook up of the external components, which are the sensor antenna, reporting antenna, the combination siren/strobe and a spare. Also on the front of the box is the manual pull station. Other external features include a place to plug in the AC power/battery recharging cord on the side of the unit and a small 1.75-inch diameter window on the back for the UV sensor.

The lid is held on by four steel latches. Removing the lid allows access to a 9 inches wide by 9.5 inches long by 4 inches high aluminum storage tray, which contains the AFS system peripherals. These include the smoke detector, the two system antennas, the siren/strobe and its cable (Figure 21).

Below the storage tray are all the electronics mounted on telescoping equipment rack. When extended, the overall height of the AFS is 31.5 inches, which allows easy access to the equipment. The major electronic components inside are the BT2-3 circuit board, transmitter/receiver modules, interface/relay assembly, UV flame detector, wireless sensor receiving unit and the 12 volt 6.5 AH rechargeable battery (Figure 22).



D. PROTOTYPE TESTING

Specific tests were conducted to evaluate the performance in five key areas, which are: (1) RF transmission qualities; (2) stand-by duration of the system; (3) proper hardware operation (Manual Pull Station); (4) fire stimulus sensitivity and reporting; and, (5) distance testing of the wireless smoke detectors.

The testing was carried out at three locations. Field testing of the AFS RF transmission qualities in actual cargo aircraft was done at Fairchild AFB near Spokane, Washington on May 21, 1992 and again on June 12, 1992. Live fire testing, including distance testing of the smoke detectors, was done at Applied Research Associates' remote test site (30 miles east of Denver, Colorado) between July 21 and August 5, 1992. The remaining tests, duration and manual pull were done at ARA's Lakewood, Colorado offices during the same period.

The instrumentation used to measure and record data for this test series was the same equipment as described for the previous series (Section 3.4.1). The one exception is that a Radio Frequency Spectrum Analyzer was used during the transmission testing at Fairchild AFB. This instrument measures transmitted signal strength between the remote and central Tx/Rx.

Objectives of each of the five types of tests carried out in this series are as follows: Transmission testing at Fairchild AFB was conducted to verify and measure RF signal strength between a manual alarm condition generated on-board an actual aircraft and the receiving station over one mile away. Sixty-hour duration testing was conducted to satisfy the requirement that the AFS prototype be capable of 60 hours stand-alone continuous operation without a recharge. The Manual Pull Station tests were to verify proper operation of this hardware. Fire/smoke tests were conducted to establish that the AFS fire/smoke detectors were effective in sensing fire conditions and initiating an alarm, in the prototype configuration. Wireless smoke detector distance tests were run to gauge the maximum separation that could be achieved between the smoke detector and the AFS remote Tx/Rx, and still transmit.

1. Test Results

Transmission testing was conducted over two, nonconsecutive days. Both days produced successful results. The first day established that the AFS could transmit alarm messages through the structure and skin of a cargo plane (C-135) to the base fire department. The alarms were being generated by different detectors placed in various locations in and around the aircraft. The second day evaluated a suitable, collapsible replacement antenna for the standard but awkward BSA-1 Omnidirectional antenna with ground plane. While placed inside the cargo bay of the aircraft, both antennas could transmit signals to the base fire department, approximately 1.1 miles away.

The AFS prototype did not successfully complete any of the four 60-hour duration tests. In all of the test series, this was the one area in which the prototype, in its current configuration, could not meet the objective. The 6.5 amp-hour rechargeable 12 VDC

battery delivered with the prototype did not match the power consumption requirements of all components. In its current configuration, it is estimated that the AFS is continuously reliable for approximately 36 hours. The AFS could meet the requirement with a larger or multiple batteries, but would require some modification.

Manual pull station testing was successful. The handle was utilized many times and under different situations. The correct alarm message was always received at the central Tx/Rx.

Thirteen live fire/smoke tests were conducted to test AFS prototype performance against Class A, B and C type fire stimulus. Because the configuration and equipment of the prototype differed somewhat from that of the breadboard design, the layout of equipment in the test structure was a little different. In the Task 2 test series, it was shown that the most efficient location for the smoke detector was from about six feet above floor level, extending up to ceiling height. The smoke detector(s) for the prototype are wireless remote units; therefore, there is no physical connection between the smoke detector and the remote Tx/Rx. Because of this configuration, the remote Tx/Rx part of the prototype was placed always on the floor, directly below the smoke detector and directly across the room from the fire source pan. Smoke detector height varied from test to test at either 6 feet or 9 1/2 feet (ceiling height). Layout of equipment for this test series is shown in Figure 23.

Fire and smoke stimulus for the various classes of fires were generated by the following means: Class A consisted of igniting identical quantities of paper/trash (cardboard, rags, weeds, etc.). The Class B source was Jet-A fuel about 1/8 inch deep in a 12-inch diameter pan. The fuel was typically difficult to ignite, so a small piece of wadded newspaper, soaked in the fuel, aided in ignition. Class C used a handful of electrical wiring, four types, cut into eight-inch lengths and placed on a preheated hot plate (on high) which would burn off the insulation.

Two electrical wiring smoke source tests were performed -- one at each of the different heights. Although smoke could be seen emanating from the burning wires on the hot plate, the smoke in the structure never could build to a dense enough level to trigger an alarm. An offensive odor and potentially toxic fumes were produced during the duration of the tests, which lasted up to seven minutes.

Two tests of the UV sensor were successful -- one being generated by a Class A fire, and the other by a Class B fire. Both alarms were generated almost instantaneously as soon as the flames were in the field of view of the sensor. The correct alarm messages were received at the central Tx/Rx.

Finally, the responsiveness of the prototype's smoke detector was tested against Class A and B fires. As stated earlier, the position of the detector also was changed from test to test. The tests were completed with success each time obscuration levels rose above 2.5 percent per foot (the manufacturer's rating). Two documented Class A tests did not go into alarm as the smoke did not build above the triggering point. The average obscuration level at which alarms did occur was 4.8 percent per foot. Response times ran

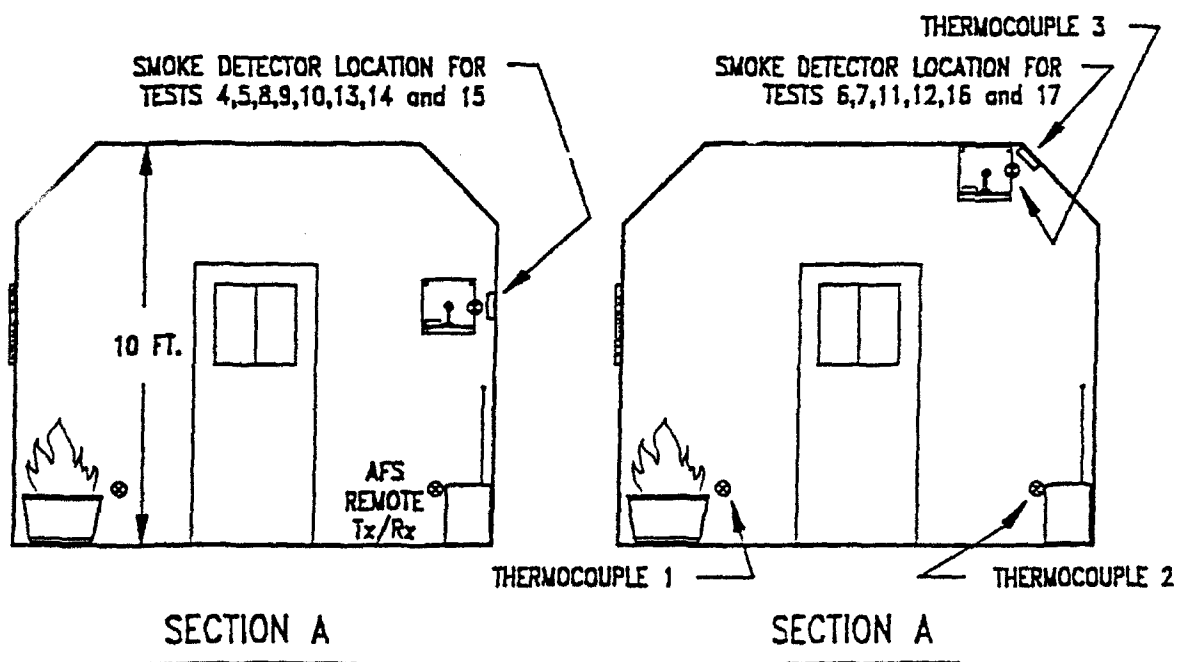
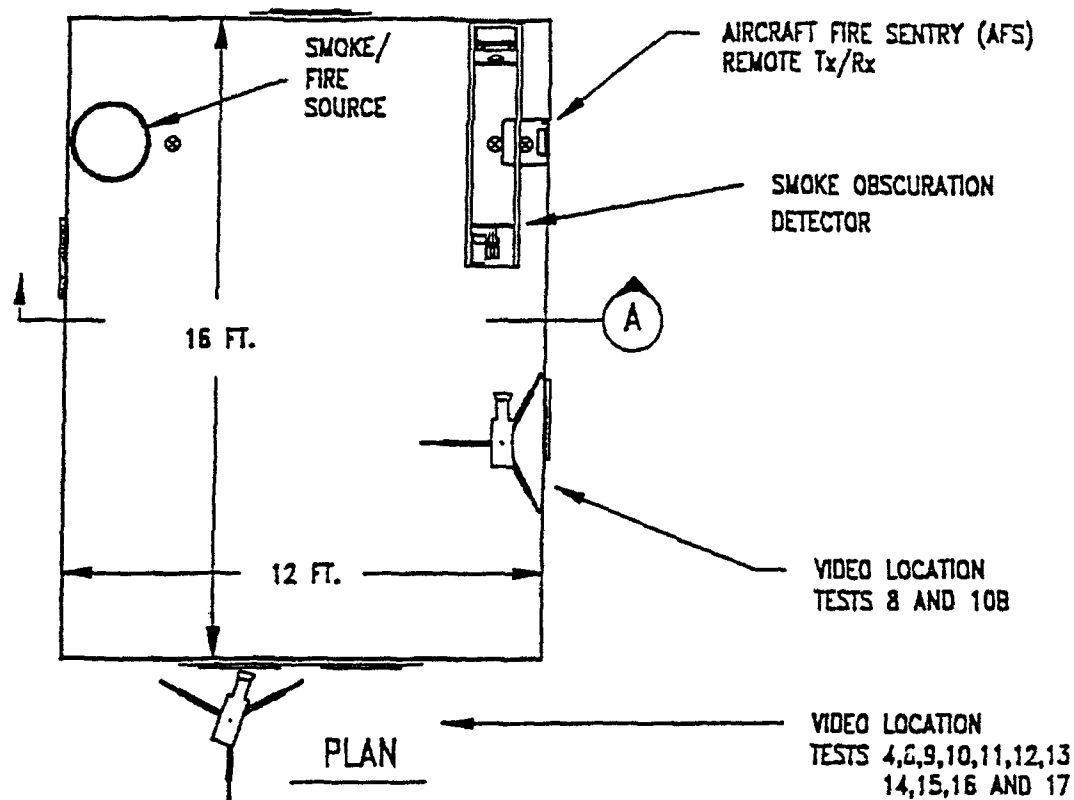


Figure 23. Equipment Layout in Structure

from 50 to 237 seconds. According to recorded thermocouple data near the smoke detector, temperature increases were noted in this area high enough to trigger an alarm, often sooner than the point at which the smoke sensor triggered. Therefore, it will be recommended that heat detectors be integrated with the wireless remote smoke detector for any subsequent design of the AFS. Photographs of a typical test setup can be seen in Figures 24 through 27. A quick look summary of Task 3 Live Testing is in Table 3. Examples of obscuration and temperature plots for this series are shown in Figures 28 and 29.

The last test of the prototype was distance testing between the wireless remote smoke detector and the remote Tx/Rx. It was established that reliable transmissions occurred at a maximum distance of 60 feet. This was a linear distance with no obstacles between the two units.

Detailed documentation of the Task 3 test series is found in Appendix C.

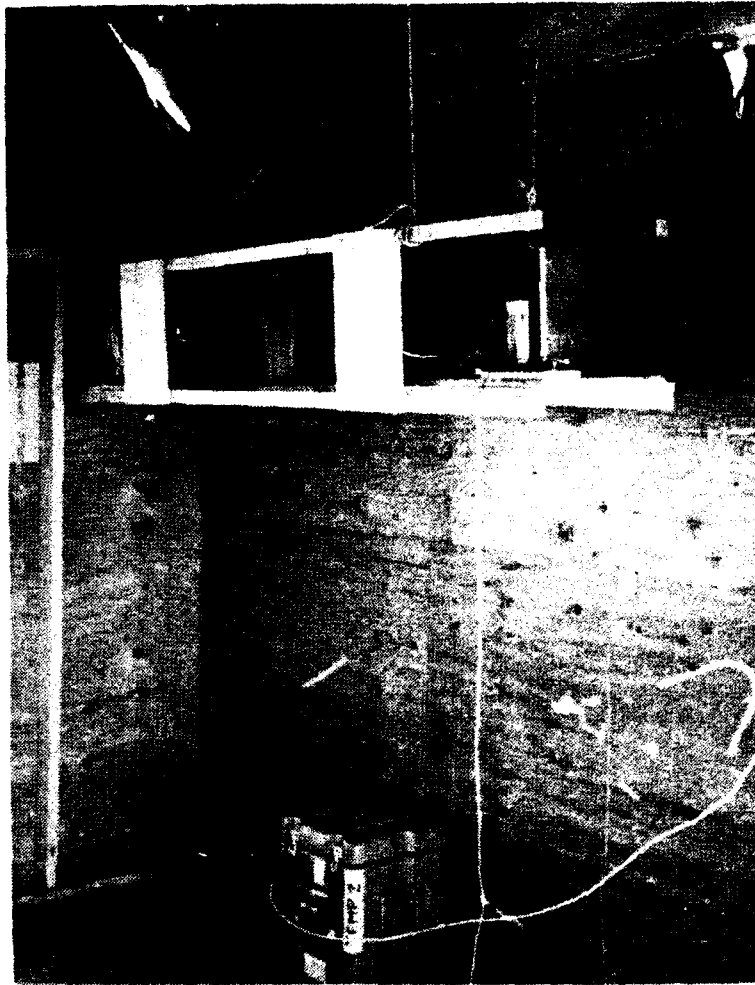


Figure 24. Smoke Obscuration Detector Installed at 6-Foot Height in Test Structure

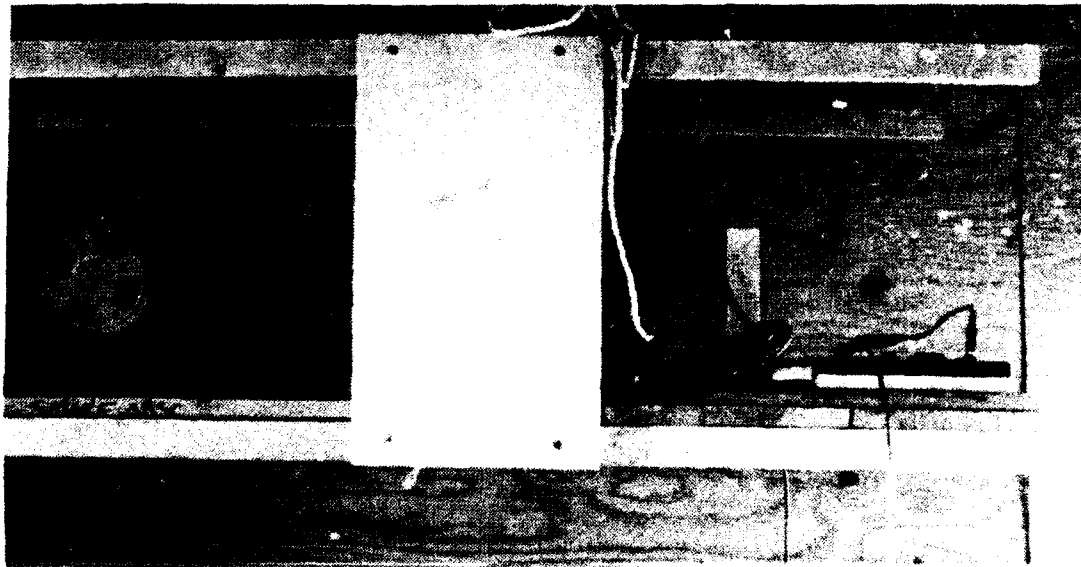


Figure 25. AFS Smoke Detector and Smoke Obscuration Photocell

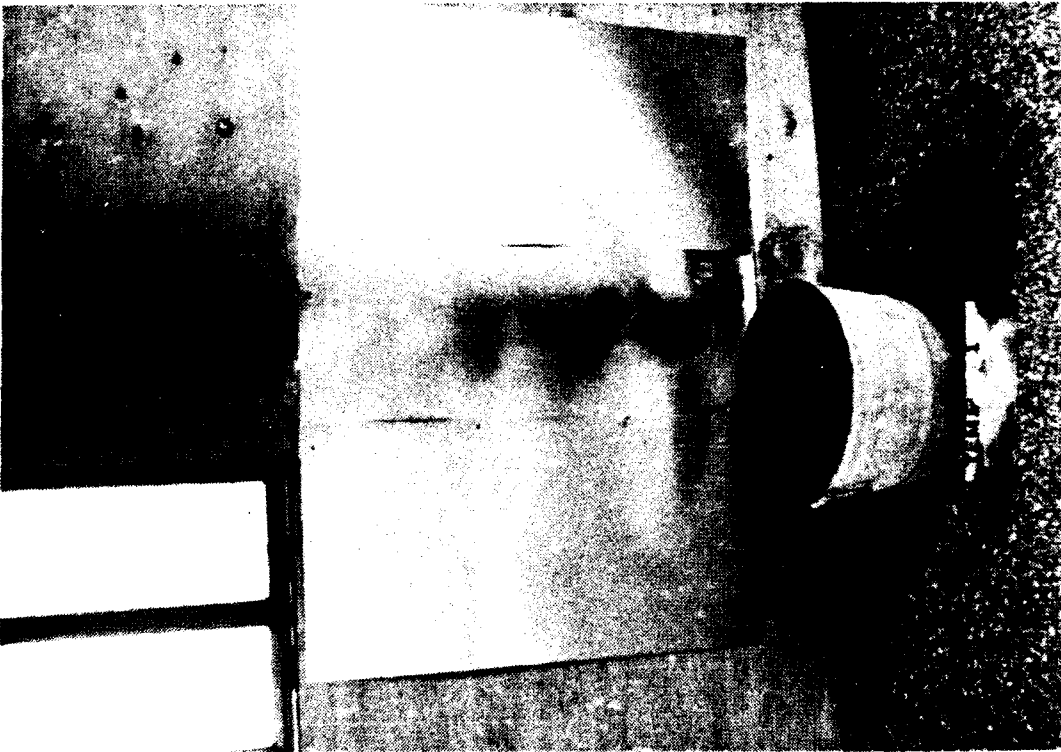


Figure 26. Fire Source Pans and TEMP1 Location

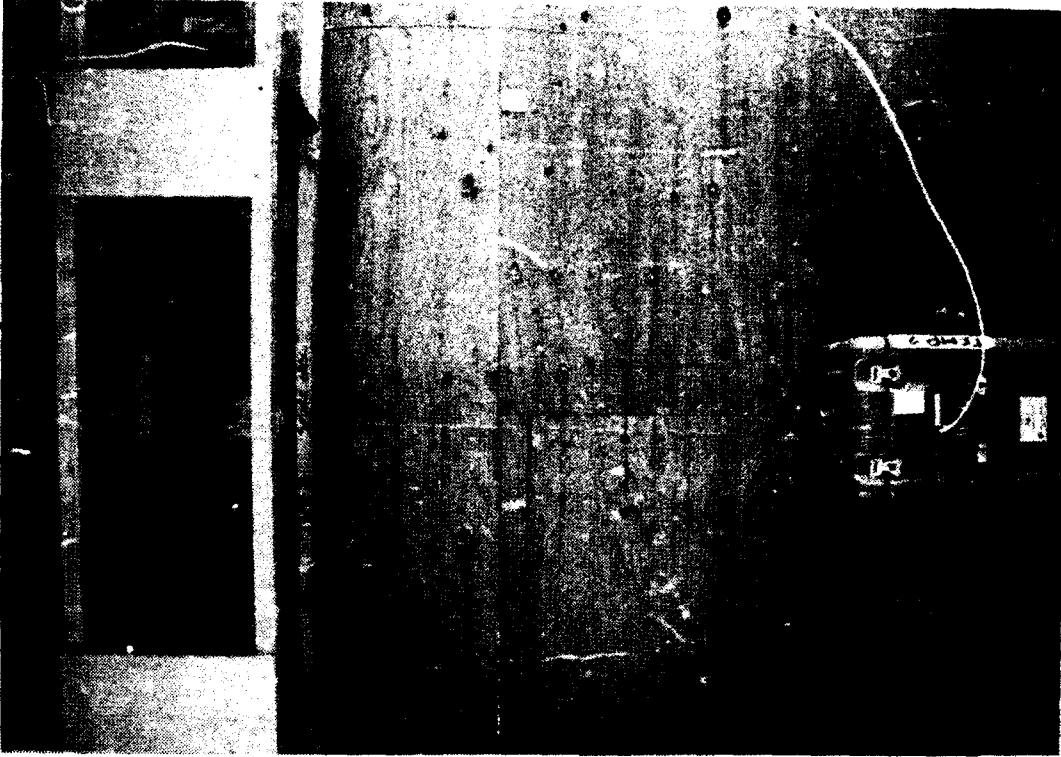


Figure 27. Typical AFS and Smoke Detector Locations,
and TEMP2 and TEMP3 Locations

AIRCRAFT FIRE SENTRY

TASK 3 -- TEST 17

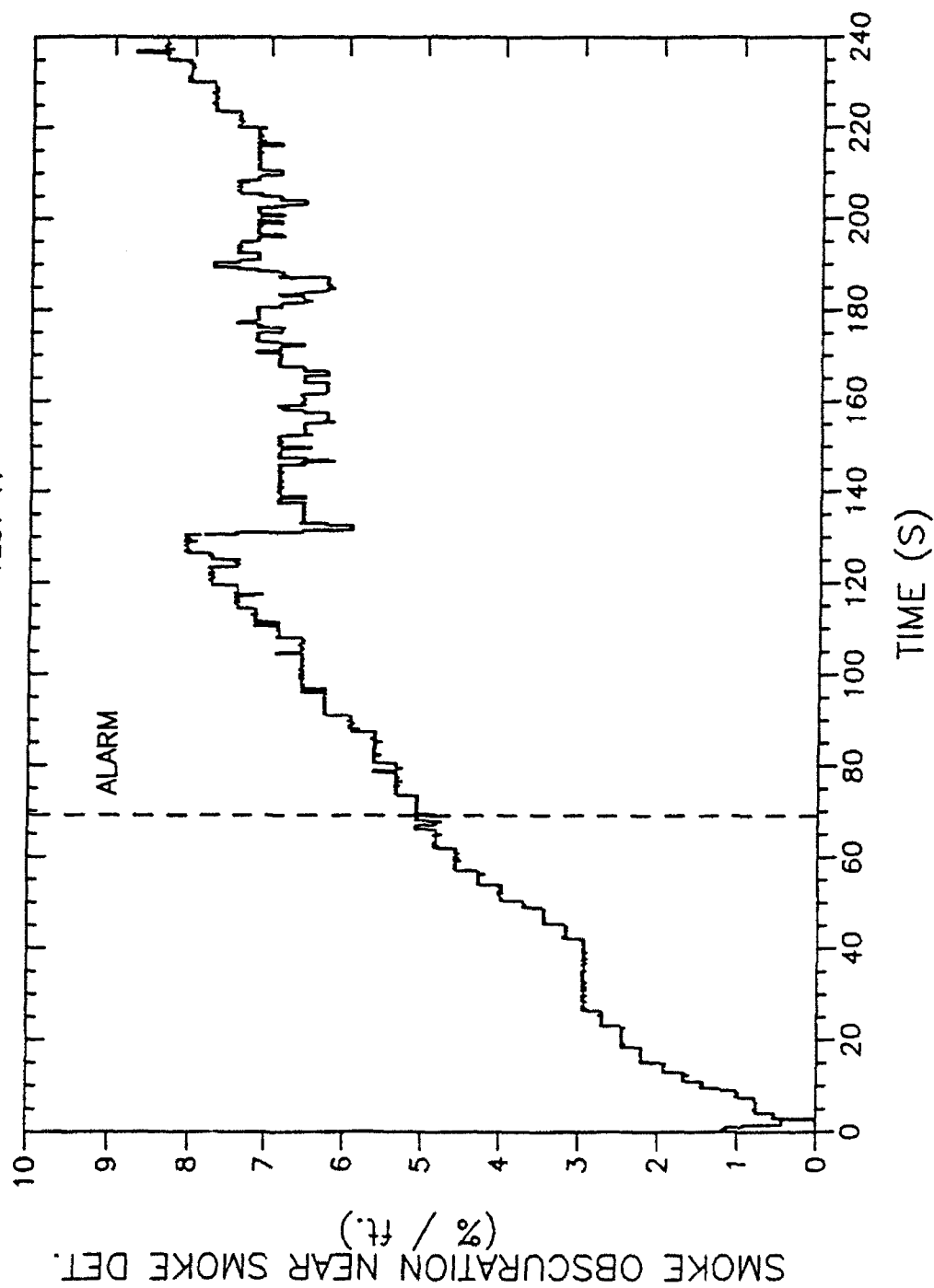


Figure 28. Smoke Obscuration -- Test 17

TABLE 3. SUMMARY OF TASK 3 LIVE FIRE TESTING

Live Test No.	Smoke = S Fire = F	Source	Detector	Smoke Detector Height	Test Duration to Alarm	Max. Temp. at Smoke Detector	Smoke Obscuration at Alarm	Remarks
4	S	Electrical Wiring	Wireless Smoke	6 ft.	No alarm	N/A	(1.1%)	Melting wire never put off much smoke. No alarm. Very bad smell. No need to run a repeat test.
6	S	Electrical Wiring	Wireless Smoke	9.5 ft.	No alarm	N/A	(0.4%)	Melting wire never put off much smoke. No alarm. Very bad smell. No need to run a repeat test.
8	F	Paper/Trash	UV Flame	N/A	77 sec.	110°F @ 105 sec.	N/D	77 seconds misleading. Alarm sounded when flames grew higher than the walls of the flame bucket.
9	F	Paper/Trash	Wireless Smoke	6 ft.	No alarm	170°F @ 65 sec.	(2.5%)	Trash fire not smokey enough to alarm. Temp. reached triggering levels.
10	F	Paper/Trash	Wireless Smoke	6 ft.	No alarm	140°F @ 100 sec.	(1.4%)	Trash fire not smokey enough to alarm. Temp. reached triggering levels.
10b	F	Paper/Trash	Wireless Smoke	6 ft.	143 sec.	180°F @ 150 sec.	6.0%	More trash added for a larger, smokier fire. Temp. levels also increased.
11	F	Paper/Trash	Wireless Smoke	9.5 ft.	112 sec.	140°F @ 75 sec.	3.9%	Alarm at detector - yes. No alarm message received at AFS or the central Tx/Rx.
12	F	Paper/Trash	Wireless Smoke	9.5 ft.	237 sec.	190°F @ 90 sec.	N/D	Trash fire not very smokey. Took a while for density to build. Temp. at high level prior to smoke alarm.
13	F	Jet-A Fuel	UV Flame	N/A	Instantaneous	N/D	N/D	Receiver module at central Tx/Rx inoperative.
14	F	Jet-A Fuel	Wireless Smoke	6 ft.	207 sec.	90°F @ 240 sec.	5.9%	Done shortly after Test 14. Possible lingering smoke by-products in shelter causing quicker response time.
15	F	Jet-A Fuel	Wireless Smoke	6 ft.	50 sec.	110°F @ 80 sec.	5.3%	Done shortly after Test 16. Possible lingering smoke by-products in shelter causing quicker response time.
16	F	Jet-A Fuel	Wireless Smoke	9.5 ft.	122 sec.	110°F @ 160 sec.	3.5%	
17	F	Jet-A Fuel	Wireless Smoke	9.5 ft.	70 sec.	120°F @ 130 sec.	4.6%	

N/A = Not Applicable

N/D = No Data

AIRCRAFT FIRE SENTRY

TASK 3 -- TEST 17

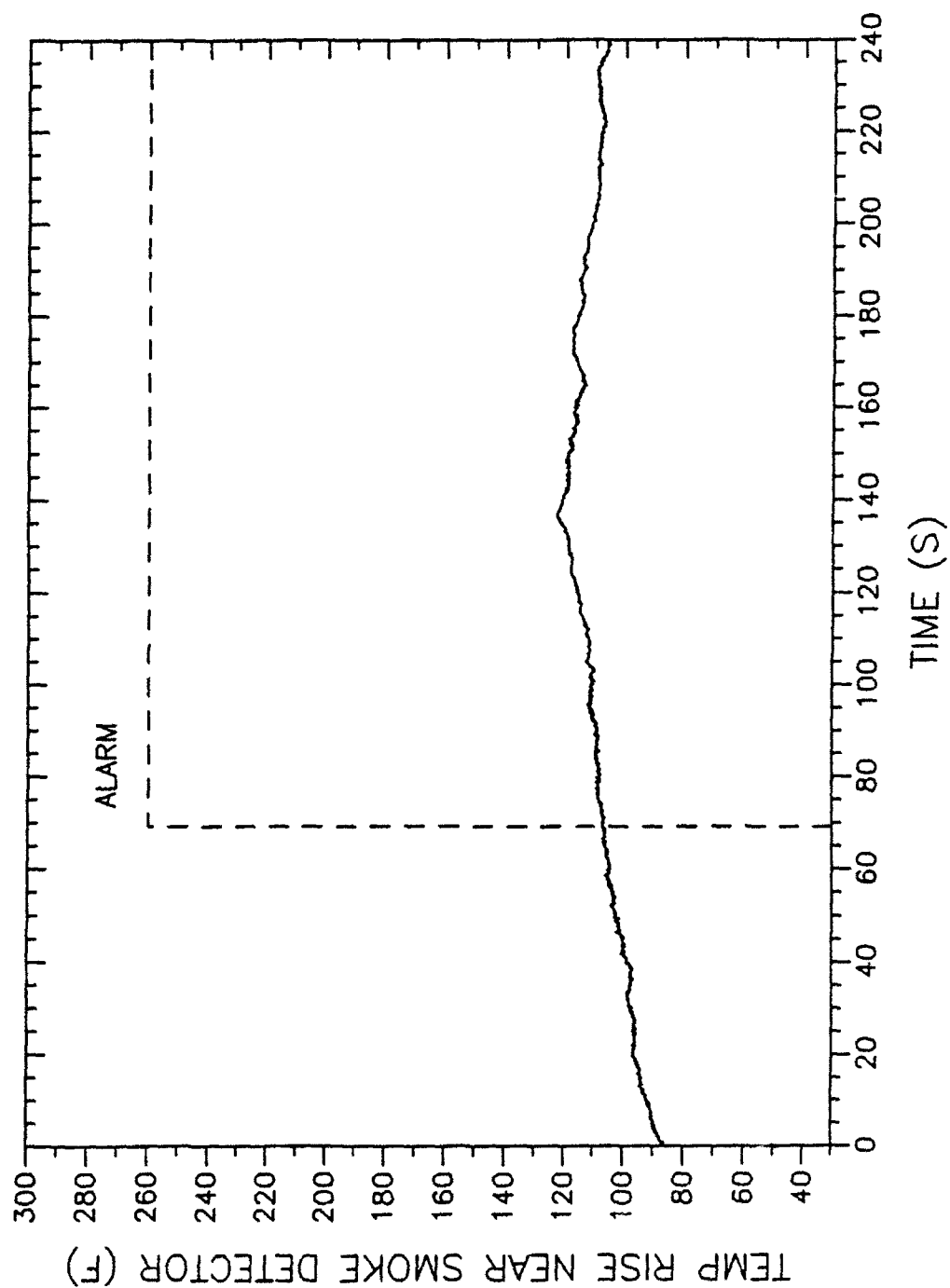


Figure 29. Temperature -- Test 17

SECTION V

CONCLUSIONS

The prototype Aircraft Fire Sentry system has essentially passed all tests as set forth in the Task 3 Test Plan with the exception of the 60-Hour Duration Test. The 6.5 AH rechargeable battery does not have the capacity to power the AFS in its current configuration for the full 60 hours. Current draw for the AFS system was measured at 0.116 amperes. In theory, this battery has a capacity of $6.5 \text{ AH} / 0.116 = 56$ hours. Under operating conditions, it is estimated that the system is reliable through about 36 hours based on the drop in voltage over time. This suggests that a larger battery is required to meet the 60 hours in the system's current configuration.

To have effective UV flame detection coverage, the prototype AFS would need additional UV sensors -- one looking out each side of the unit. They should be placed further outward so each would have a better cone of vision. The UV sensor currently installed in back should be moved to look out the front. Assuming the AFS would be placed in the aircraft with its back against the fuselage wall, this could give the assembly close to a 270° cone of vision. It would also increase the unit's power requirements, which would require an even larger battery.

Since the early stages of this project, the Machine Vision flame detection system has been considered a possible candidate for flame detection in the AFS. That system, however, has been under development during the entire duration of this project, and no unit was ever obtained for AFS integration or testing purposes. What is known is the rough size and power requirements, which are 10 inches by 10 inches by 4 inches and 25 watts (12 VDC @ 2.1a). These power requirements are substantially higher than three standard UV sensors. Cost of a Machine Vision system is unknown at this time.

The wireless smoke detectors were responsive within their operating range and seem to be a good choice for deployment in the aircraft. The length of the largest cargo bay is approximately 150 feet (C-5) which would require at least 2 detectors, as their range was determined to be 75 feet maximum. In this arrangement, the AFS would be placed mid-bay and a detector placed approximately midway between the AFS and the ends of the bay. On the basis of response times to the real fire/smoke testing, the best height for the smoke detector is up near the ceiling -- certainly above the level of any open doors or windows, etc.

Data obtained during the live fire/smoke series of testing have shown that temperature in the structure near the smoke detector sometimes increased to heat sensor triggering levels before the smoke alarm sounded. It is recommended that for any subsequent model of AFS, a suitable heat sensor be integrated with the portable wireless smoke detector.

The prototype AFS can be transported and deployed by a single person in a matter of minutes. It would be desirable, however, to decrease its bulk somewhat in size and weight. This would probably require considerable redesign.

The main system antenna is a 40-inch collapsible with a magnetic base and a 12-foot length of cable. The best place for the magnetic base to be placed is on the top steel carrying handle on the AFS.

The approximate cost for each AFS prototype copy, as is, is \$5,000.00.

The prototype AFS could be produced and deployed as is. Its performance could benefit from a few modifications; namely, an integral heat sensor and a more powerful battery. Through testing, the AFS has been established as an effective means of detecting and reporting fires on unattended large cargo aircraft.